ANALYSIS OF STORM WATER RUNOFF DRAINAGES

IN ADDIS ABEBA CITY

CASE STUDY: CMC ROAD

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MASTER OF BUSINESS ADMINISTRATION

ADDIS ABABA SCIENCE AND TECHNOLOGY

UNIVERSITY

FEBRUARY 2018

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By

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A Thesis submitted to

The department of Business and Management for the Partial Fulfillment of the Requirements for the

Degree of Master of Business Administration in Construction Management

ADDIS ABABA SCIENCE AND TECHNOLOGY UNIVERSITY

FEBRUARY 2018

DECLARATION

I, Fekadu Zeleke Ayele, hereby declare that this thesis entitled "Analysis of Storm Water Runoff Drainages" was composed by myself, with the guidance from my Advisor, that the work contained herein is my own except where explicitly stated otherwise in the text, and that this work has not been submitted, in whole or in part, for any other degree or professional qualification.

Fekadu Zeleke Ayele

February 2018

CERTIFICATE

This is to certify that the thesis prepared by **Mr. Fekadu Zeleke Ayele** entitled "**Analysis of Storm Water Runoff Drainages**" is submitted in fulfillment of the requirements for the Degree of Master of Business Administration and it complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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DEDICATION

This research is dedicated to my dear mom, Workitu Gelmessa, who gave her life out to get me here. Just ‘thank you’ is not enough to express my gratitude.

ABSTRACT

Essentially, drainages are structures that collect, convey and discharge runoff from the surface of road pavements and adjacent catchment areas to artificial or natural waterways like ditches, channels, rivers, streams, ponds, lakes etc.

Drainage problems occur either due to design, usage and/or construction defects. As observed in most parts of Addis Ababa city roads, storm runoff overflow drainage channels, spew debris, inundate pavements, block traffic movement and cause accidents. Water on the pavement can interrupt traffic, reduce skid resistance, increase potential for hydroplaning, limit visibility due to splash & spray and cause difficulty in steering a vehicle when the front wheels encounter puddles. Moreover, since the light train transport service uses electric power to operate, runoff flow over the rails could pose electrical hazard to passengers.

The objective of the research is, thus, to identify the main problems of storm runoff drainages and of course investigate the causes and suggest viable solutions to curtail similar occurrences and mitigate the adverse effect.

Thus, data is collected using; Questionnaire, field survey/site investigation, observation, interviews, photographs, public discussions, etc. hence compiled and analysed through Wrangling, cleansing, and shaping data, using Excel's analysis tool pack. Six offices that have direct and indirect dealing with storm runoff drainage and residents living around the corridor of the study area were contacted and given the questionnaire.

The finding is that the main problem associated with storm runoff drainages are clogging by debris, rubbish & sedimentation and the causes are identified to be inadequate study of the soil & topography, insufficient channel size, dumping of rubbish into the channels by residents and poor construction workmanship.

Therefore, establishing a legally mandated and dedicated drainage department in Municipalities to regulate, guide and monitor design and construction of storm runoff drainages, to conduct regular inventory of drainage assets & furniture, to draft drainage master plan, to create awareness in solid waste disposal, to regularly clean the channels and upgrade the existing structures will significantly alleviate the problems.

ACKNOWLEDGEMENTS

Above all, glory be to the almighty God for his presence, unspeakable gift, help and protection during my work and for making my life meaningful in every aspect. I would like to express my deepest and sincere gratitude to my advisor Prof. Belete Kebede, for his critical review, constructive comments and overall guidance during my research work. My special thanks also goes to the late Dean, Dr. Atsede Mekuria (PhD), for her facilitation, encouragement and support.

I am grateful for the assistance rendered by Mr. Gedeon Girma, in data collection, printing and binding my research documents.

I am indebted to my wife Ms. Rahel Girma for her unflinching support and care during all my studies and to my family and friends for their encouragement.

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ABBREVIATION

AASHTO - American Association of State Highway and Transportation Officials

BOD - Biochemical Oxygen Demand

BS - British Standard

CBR - California Bearing Ratio

CMC - Cooperativa Muratori e Cementisti (an Italian Construction Company)

COD – Chemical Oxygen Demand

DDF – Depth – duration – Frequency

ERA - Ethiopian Roads Authority

HDPE - High Density polyethylene

ID - Inner diameter of a pipe measured from inside the wall

IDF - Intensity – duration – frequency

MDPE - Medium Density Polyethylene

OD - Outer diameter of a pipe measured from outside the wall

OSHA - Occupational Safety and Health Administration

PCB – Poly Chlorinated Biphenyl

ROW - Right-of-way, which is a distance of public access

SUDS - Sustainable (urban) drainage systems

DEFINITIONS

Aquifer—Geologic formation or group of formations through which water flows or within which water is stored

Base Drainage System—Permeable drainage blanket under a paved roadway, parking area, and so on

Channel (closed or open) -A pipe or perceptible natural or artificial waterway that periodically or continuously contains moving water

Culvert - A closed conduit for the passage of water under an embankment/ roadway

Drainable Water - Water that readily drains from soil under the influence of gravity.

Evapotranspiration - combined process of moisture evaporation from the soil and transpiration from plants

Frost Action - Freezing and thawing of soil moisture.

Geo-composite - Geo-synthetic materials for collecting and transporting water while maintaining soil stability

Geology—Surface formations

Geomembrane—Sheet material intended to form an impervious barrier

Geo-synthetic—Synthetic material or structure used as an integral part of a project, structure, or system. Within this category are surface drainage and water control materials such as geomembranes, geotextiles, and geo-composites

Geotextile—Woven or nonwoven thermoplastic sheet material intended to allow the passage of water, but not fines

Grade—May refer to either (1) the slope of the drain in vertical units or horizontal units; or (2) the specified vertical location of the drain, depending on the context in which it is used and without collecting fines at the soil— textile interface

Hydrology - The science dealing with the disposition of water on the earth or Movement of water in nature

Infiltration - Abstraction process in which water flows or is absorbed into the ground (Movement of water into the soil)

Intensity - The rate of precipitation, usually in inches or mm/hour

Longitudinal Drainage System - Drainage system parallel to a roadway, parking area, so on

Overland flow - water which travels over the ground surface to the stream channel, usually limited to a maximum length of 100 feet

Percolation Rate - Downward movement of water through soil

Permeability - Rate at which water passes through a porous medium

Relief Drain - A product or construction that accelerates the removal of drainable surface water

Runoff - Precipitation remaining after appropriate hydrologic abstractions are accounted for

Runoff coefficient - Empirical parameter used to calculate rainfall excess as a fixed percentage of precipitation; it accounts for interception, surface storage, and infiltration

Seepage - Movement of drainable water through soil and rock

Soil Texture - Relative proportions of sand, silt, and clay particles in a soil mass

Storm Water Runoff - the direct response of a watershed to precipitation and includes the surface and subsurface runoff that enters a ditch, storm drain, stream or other concentrated flow during and following the precipitation. Runoff that occurs on surfaces before reaching a channel is also called non-point source pollution.

Subsurface Water - All water beneath the ground or pavement surface. Usually referred to as groundwater.

Transverse Drainage System - Drainage system usually at some angle to a roadway or other paved surface.

Water Table - Upper limit of free water in a saturated soil or underlying material

Time of concentration - The time of travel from the hydraulically most distant point of a watershed to the design point

Watershed - An area bounded peripherally by a drainage divide that concentrates runoff to a particular water course or body; the catchment's area or drainage basin from which the waters of a stream are drawn

CHAPTER ONE

1. INTRODUCTION

1.1 Background of the study

Storm water drainage facilities are part of urban infrastructure elements whose design require due attention and careful consideration.

In Ethiopian context, where watersheds of many urban centers receive significant amount of annual rainfall with high intensity, control of runoff at source, flood protection and safe disposal of excess water/runoff through proper drainage facilities becomes very critical.

Drainage problems in urban areas include flooding, deterioration of roads, land degradation, sedimentation, blockage of drainage facilities, water logging, etc.

With urbanization, impermeability increases with introduction of impervious surfaces (like paved roads, parking lots, houses etc.) and consequently drainage pattern changes, concentration of flow increases, overland flow gets faster and as a result flooding occurs and environmental problems such as land degradation increases. It is a crucial problem facing the existing and future urban infrastructures.

In addition to these problems, drainage facilities in most urban centers of the country are nearly absent or have a very low coverage. Planning and design rarely guide construction or provision of such facilities and management.

Storm water drainage is an important component in the design of roadways, because it affects serviceability and usable life of the roadway, including structural strength of the pavement. Adequate longitudinal and cross-drainage facilities will limit the buildup of pond against side of roadway embankments and avoid overtopping towards the roadway. If ponding occurs on the carriageway, hydroplaning (skidding of vehicles) will ensue and becomes a major safety concern to traffic and passengers.

Therefore, design of drainage structures shall be accorded careful consideration, research and planning.

1.2 Statement of the problem

Essentially, drainages are structures that collect, convey and discharge runoff from the surface of road pavements and adjacent catchment areas to artificial or natural waterways like ditches, channels, rivers, streams, ponds, lakes etc.

Drainage problems occur either due to design, usage and/or construction defects.

As observed in most parts of Addis Ababa city roads, storm runoff overflow drainage channels, spew debris, inundate pavements, block traffic movement and cause accidents. Overflow problem is partly the outcome of solid waste litters dumped in to the channel by residents living around the drainage. The litters obstruct smooth flow of the runoff forcing it to deposit sediments hence clog the channel. Moreover, since ditches are not provided to convey runoff from adjacent catchment areas, it is a normal scene to observe pools lying over streets and alleyways. These in addition to becoming hatching spot for mosquitoes; they limit vehicular and pedestrian movements and stain houses & vegetation with splashes notwithstanding the damage to the surface and subbase of the road. The damage ranges from disturbance of structural integrity, property damage to loss of life. This is costing a hefty sum and drains a scant capital resource from a staggering economy.

Water on the pavement can interrupt traffic, reduce skid resistance, increase potential for hydroplaning, limit visibility due to splash and spray and cause difficulty in steering a vehicle when the front wheels encounter puddles. Hydroplaning is a phenomenon, different from skidding, which occurs when the tires lose contact with the pavement and begin to ride on a thin film of water. At this point, any accelerating, braking, or cornering forces may cause the driver to lose control. Moreover, since the light train transport service uses electric power to operate, runoff flow over the rails could pose electrical hazard to passengers.

Furthermore, design of drainage structures are highly dictated by subjective view of the designer who gauge them only from a point of budget and prevailing condition of the road corridor under design instead of considering them as an integrated subsequent activity that technically connect to each other and are required to accommodate upstream accumulated volume of flow and velocity. Unfortunately, drainages are considered as an accessory to road works rather than as a standalone project designed to integrate surrounding flows together with pavement runoff. These all drainage associated problems cost high on maintenance and rework thus divert a significant amount of money from the depleting coffer that could otherwise have been used in other essential economic sectors.

Figure 1.1. Storm runoff inundating a roundabout around Salite Mihret church, A.A (Courtesy: Fekadu Zeleke)

1.3 Research Questions

1) What are the main problems of storm runoff drainage structures?

2) What are the causes of the problem?

3) Who is regulating the design and construction of drainage structures?

4) How to overcome the problem

1.4 Objectives of the research

a) Identify the main problems of drainage structures

b) Identify the major causes of the drainage problems

c) Advocate for active presence and enhanced intervention of regulatory organ in design and construction of drainage structures

d) Methods to control problem of storm runoff

1.5 Scope of the Research

The scope of the research is geographically limited to Addis Ababa, CMC Street whereas essence of the research is on analysis of storm runoff drainages both from the adjacent catchment areas and the road pavement. It also plans to discuss/analyze drainage policy issues in detail.

1.6 Significance of the Research

It is anticipated that uncoordinated practices associated with design and construction of drainage structures could be curtailed hence health and safety concerns will be improved and drainage related accidents will be mitigated.

Moreover, through use of integrated and improved construction approach, optimum resource utilization will be attained and there will be significant reduction of cost that would otherwise be spent on developmental projects rather than unnecessary maintenance, rework and indemnity payments. Furthermore, the research advocate on awareness creation and proper method of solid waste disposal and intends to delineate between storm runoff drainage and road pavement runoff drainage that are used interchangeably in most literatures.

Storm water management is an increasingly important consideration in the design of urban drainage systems. Storm water management practices, when properly selected, designed, and implemented, can be utilized to mitigate the adverse hydrologic and hydraulic impacts caused by drainage facilities, thereby protecting downstream areas from increased flooding, erosion, and water quality degradation.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Introduction

Urban drainage systems handle two types of flow: wastewater and storm water. Storm water (surface runoff) is then the second major urban flow of concern to the drainage engineer. Safe and efficient drainage of storm water is particularly important to maintain public health and safety (due to the potential impact of flooding on life and property) and to protect the receiving water environment. Reliable data on the quantity and quality of existing and projected storm water flows is a prerequisite for cost-effective urban drainage design and analysis.

Storm water is generated by rainfall, and consists of that proportion of rainfall that runs off from urban surfaces. Hence, the properties of storm water, in terms of quantity and quality, are intrinsically linked to the nature and characteristics of both the rainfall and the catchment.

2.2 Rainfall

The main component of the hydrological cycle forming the principal source of water on the global land areas is precipitation, which can be in liquid or solid forms. Except for melting snow already lying on the ground, it is the liquid form, rainfall, which gives the larger quantities in the shorter durations and thereby gives the drainage engineer the greater cause for concern.

The occurrence of rainfall depends on the existence of favorable atmospheric conditions, and these are found in distinctive weather patterns which give their name to recognized rainfall types. Cyclonic or depression rainfall is formed in mid-latitude depressions in both hemispheres and characteristic rainfall sequences can be identified in the associated frontal systems separating warm and cold air masses. More vigorous cyclonic rains occur in the tropical cyclones or hurricanes. Short-duration rainfalls, showers, are mainly produced in convective systems when moist rising air cools quickly. This situation operates widely in tropical regions and has been identified in frontal systems so that the classification of rainfall according to its formation is not always easy. Generalized values of rainfall intensities

Table 2.1. Rainfall type intensities, generalized (mm/h)

Intensity	**Rain - Cyclonic/Frontal**	**Showers - Conventional**
Slight	<0.5	<2.0
Moderate	0.5-4.0	2.0-10.0
Heavy	>4.0	10.0-50.0
Violent	-	> 50.0

(Source: Meteorological Office, 1969)

To complete the rainfall types, there is a composite generic type, orographic, in which rainfalls with frontal or convective origins may be enhanced by the extra altitude effects of hills or mountain ranges. Orographic rain may also be formed when homogeneous moist air is obliged to rise over high land without being initiated by a dynamic meteorological situation.

These three most recognized types of rainfall, cyclonic/frontal, convective and orographic, can each play a part in producing excess rainfall. Persistent continuous rainfall from a slow-moving depression can saturate a catchment over a few days, while localized heavy showers lasting an hour or two can produce flood situations over saturated or impervious ground. Orographic rainfall plays a major role in increasing rainfall with altitude in the upper reaches of major catchments.

2.3 Catchment

Catchment topography, channel gradients and the nature of the ground surface play a large part in determining drainage needs. Impervious surfaces of city buildings and the concrete expanses of car parks and airport runways provide a rapid response to heavy rainfall. Sandy soils and porous geological strata may readily absorb the rainfall.

2.4 Surface Run off

The transformation of a rainfall into a surface runoff involves two principal parts. Firstly, losses due to interception, depression storage, infiltration and evapo-transpiration are deducted from the rainfall. Secondly, the resulting effective rainfall is transformed by surface routing into an overland flow. Much of the rainfall that reaches the ground does not, in fact, run off.

It is 'lost' immediately or as it runs overland. The water may be completely lost from the catchment surface by processes such as by evapo- transpiration, it may be temporarily retained in depression storage or it may eventually find its way to the drainage system via groundwater.

Interception consists of the collection and retention of rainfall by vegetation cover. There is an initial retention period, after which excess rain falls through the foliage or flows to the soil over the stems. The interception rate then rapidly approaches zero. The interception loss for impervious areas is small in magnitude (<1 mm) and is normally neglected or combined with depression storage.

Depression storage accounts for rainwater that has become trapped in small depressions on the catchment surface, preventing the water from running off. Infiltration, evaporation or leakage will eventually remove the water that has been retained. Factors affecting the magnitude of depression storage are surface type, slope and rainfall return period.

2.5 Evapo-transpiration

Evapo-transpiration is the vaporization of water from plants and open water bodies and therefore its removal from surface runoff. Although it is a continuing, constant loss, its effect during short duration rainfall events is negligible. Consequently, it is normally neglected in most models or considered to be lumped into the initial losses.

The combination of open-water evaporation and transpiration from vegetation results in a loss of water from drainage areas. When considering intense rainfalls on impervious surfaces, evaporation losses can be neglected, but on natural catchments and for irrigated areas evapotranspiration (E1) on a daily or even seasonal basis may form a very significant proportion of the water balance equation:

$$\boldsymbol{P = R + \mathrm{E}\,1 + \Delta S + G}$$

Where:

P =precipitation, R =runoff, ΔS= change in storage and G =seepage to groundwater.

The main factors affecting evapotranspiration are as follows:

(a) Solar radiation, resulting in direct short-wave and terrestrial long-wave radiation, provides latent heat to convert the water into vapour and is dependent on latitude and season.

(b) Air temperature and the temperature of the evaporating surface dependent on the available radiation.

(c) Vapour pressure of the air, since this is a measure of its vapour capacity at a given temperature (e_a). The saturation deficit given by e_a.- e_d (where e_d is the saturated vapour pressure at the dew point temperature) or e_a.- e_s, (where e_s, is the saturation vapour pressure at the temperature of the evaporating surface) gives a measure of the additional water vapour the air can hold at that air temperature.

(d) Wind speed at the evaporating surface affects the air's evaporating capacity. Saturated air is moved on and drier air replacement ensures continuation of the evaporation process.

(e) In addition to these basic physical factors, the general atmospheric pressure with associated weather patterns and the character of the evaporating surface also influence evapotranspiration losses. Transpiration is also governed by the available moisture in the soil.

2.6 Infiltration

Infiltration represents the process of rainfall passing through the ground surface into the pores of the soil. The infiltration capacity of a soil is defined as the rate at which water infiltrates into it. The magnitude depends on factors including soil type, structure and compaction, initial moisture content, surface cover and the depth of water on the soil. The infiltration rate tends to be high initially but decreases exponentially to a final quasi-steady rate when the upper soil zone becomes saturated.

2.7 Storm Water Quantity

Storm water quantity is variable in duration, frequency and location. The amount of storm water runoff reaching a receiving water body will also depend upon the surface over which it travels. An increase in Storm water runoff in urban areas results in increased peak flows, which must be determined in order to design and implement any storm water works. The quality of storm water runoff is often a function of several mechanisms and the type and amount of pollutants in runoff are associated with a given land use or activity. As the case with the design of any wastewater treatment works, the incoming quality of Storm water runoff must be known prior to designing any storm water works.

The hydraulic sizing of drainage and conveyance structures in urban areas always requires estimation of peak flow rates. Peak flow is the maximum rate of flow passing a given point during or after a rainfall event. Historically, the Rational Method is the most widely used method of estimating the peak runoff rates for the design of urban drainage systems. The Rational Method is based on an empirical formula relating the peak flow rate to the drainage area, the rainfall intensity and a runoff coefficient. The Rational formula is:

Q = 0.0028 C I A (m^3/s) [Metric units]

Where

Q = peak runoff rate

C = dimensionless runoff coefficient

I = rainfall intensity for a duration that equals time of concentration (tc) of the basin (mm/hr and in/hr in metric and British units, respectively)

A = basin area (hectares and acres in metric and British units, respectively), and

The fundamental assumptions underlying the Rational Method are:

- The rainfall intensity is constant over a period that equals the time of concentration of the basin;
- The rainfall intensity is constant throughout the basin;
- The frequency distribution of the event rainfall and the peak runoff rate are identical (this assumption is true for all event-based computations);
- The time of concentration of a basin is constant and is easily determined; and
- The runoff coefficient is invariant, regardless of season of the year or depth or intensity of rainfall.

Typically, rainfall intensities are determined from Intensity-Duration-Frequency curves (IDF curves) or Depth-Duration-Frequency curves (DDF curves). These are plots of rainfall intensity (or depth) verses duration of event rainfall. The runoff coefficient C that is commonly used in estimating peak runoff rate is shown in Table 2.2.

There are a number of computer programs (models) that are available to perform hydrologic and hydraulic computations for large watersheds. However, only a few programs are designed as general application models that can be applied to a wide variety of problems in different locations. There are two types of models for doing hydrologic and hydraulic computations for a system: continuous simulation models and event-based models. These models can be used as long as the designer can demonstrate that the model is appropriate and accurate.

Table 2.2. Runoff coefficients for urban areas

Type of drainage area	**Runoff coefficient**
Business:	
Downtown areas	0.70-0.95

Neighborhood areas	0.50-0.70
Residential:	
Single-family areas	0.30-0.50
Multi-units, detached	0.40-0.60
Multi-units, attached	0.60-0.75
Suburban	0.25-0.40
Apartment dwelling areas	0.50-0.70
Industrial:	
Light areas	0.50-0.80
Heavy areas	0.60-0.90
Parks, Cemeteries	0.10-0.25
Playgrounds	0.20-0.40
Railroad yard areas	0.20-0.40
Unimproved areas	0.10-0.30
Lawns:	
Sandy soil, flat, 2%	0.05-0.10
Sandy soil, average, 2 to 7%	0.10-0.15
Sandy soil, steep, 7%	0.15-0.20
Heavy soil, flat, 2%	0.13-0.17
Heavy soil, average, 2 to 7%	0.18-0.25
Heavy soil, steep, 7%	0.25-0.35
Streets:	
Asphaltic	0.70-0.95

Concrete	0.80-0.95
Brick	0.70-0.85
Drives and walks	0.75-0.85
Roofs:	0.75-0.95

Source: (Water security agency, storm water guidelines, EPB322, January 2014)

2.8 Storm water Quality

Numerous studies have indicated that there can be significant pollution in receiving waters due to storm water runoff. The pollutant loading from urban/rural runoff may be similar to that of wastewater effluent and industrial discharges and have significant impacts on potable water supply, aquatic habitat, recreation, agriculture and aesthetics.

Storm water runoff is usually high in suspended solids and organic matter that exert oxygen demand in the receiving waters. Other pollutants or physical conditions associated with urban/rural runoff that are harmful to receiving waters include nitrogen/phosphorus, temperature, pathogens, metals, hydrocarbons, organics and salt.

Significant impacts on receiving waters associated with storm water discharges include:

- water quality changes (short-term) during and after storm events including temporary increases in the concentration of one or more pollutants, toxins or bacteria levels;
- Long-term water quality impacts caused by the cumulative effects associated with repeated storm water discharges from a number of sources; and physical impacts due to erosion, scour and deposition associated with the increased frequency and volume of runoff that alters aquatic habitat.

Pollutants frequently found in storm water runoff, their source and the impact on receiving waters are summarized in Table 2.3.

Table 2.3. Summary of main storm water pollutants, sources, effects, and related impacts

Storm water Pollutant	**Sources**	**Effects**	**Related Impacts**
Nitrogen/ Phosphorus (Nutrients)	Urban landscape runoff (fertilizers, detergents, plant debris, sediments, dust, gasoline, tires); agricultural runoff (fertilizers, animal waste); failing septic systems.	Phosphorus is the limiting nutrient in most freshwater systems. Nitrogen is the limiting nutrient in most saltwater systems, but can be a concern in streams as well	Algal growth; reduced clarity; lower dissolved oxygen (DO); release of other pollutants. Nutrients can limit recreational values (swimming, boating, fishing and other uses), reduce animal habitats and contaminate water supplies
Suspended solids	Construction sites; other disturbed and non-vegetated lands; eroding banks; road sanding; urban runoff.	Increased turbidity and deposition of sediment.	Increased turbidity; lower DO; deposition of sediments; smothered aquatic habitat.
Pathogens (bacteria/ viruses	Animal waste; urban runoff; failing septic systems	Presence of bacterial and viral strains. Bacteria levels are usually high in summer when warm	Human health risks via drinking water supplies; contaminated shellfish growing areas and swimming beaches.

		temperatures are beneficial to reproduction.	
Metals	Industrial processes; normal wear of automobile brake lines and tires; automobile emissions and fluid leaks; metal roofs.	Increased toxicity of runoff and accumulation in the food chain	Toxicity of water column and sediment; bioaccumulation in aquatic species and through the food chain.
Hydrocarbons (oil and grease, Polycyclic Aromatic Hydrocarbons (PAHs))	Industrial processes; automobile wear; automobile emissions and fluid leaks; waste oil.	Degraded appearance of water surfaces; limiting water and air interactions (lower DO). Hydrocarbons have a strong affinity for sediment.	Toxicity of water column and sediment; bioaccumulation in aquatic species and through the food chain
Organics (pesticides, polychlorinated biphenyl/PCBs, synthetic chemicals)	Pesticides (herbicides, insecticides, fungicides, etc.); industrial processes.	Increased toxicity to sensitive animal species and fishery resources and accumulation in the food chain.	Toxicity of water column and sediment; bioaccumulation in aquatic species and through the food chain.
Salt (sodium, chlorides)	Salting of roads and uncovered salt	Toxicity to organisms, reduction of	Toxicity of water column and sediment. Salt can cause the

	storage	fishery resources and increased levels of sodium and chloride in surface and groundwater. Could stress plant species respiration processes through their effect on soil structure.	loss of sensitive animal species, plant species, and fishery resources and contaminate surface and groundwater.

Source: (Water security agency, storm water guidelines, EPB322, January 2014)

2.8.1 Nature and sources of pollutants

Mechanisms of pollution

Drainage discharges which affect water quality can be categorized into four groups:

1) Those which contain oxygen-demanding substances, either organic, such as fecal matter, or inorganic. Heated discharges, such as cooling waters, reduce the concentration of dissolved oxygen.
2) Those which contain substances which physically hinder re-oxygenation at the water surface, such as oils.
3) Discharges containing toxic compounds, including ammonia, pesticides and some industrial effluents.
4) Discharges high in suspended solids, which inhibit biological activity by excluding light from the water or by coating the bed.

Discharges containing oxygen-demanding substances are assessed by measuring the amount of oxygen required for their stabilization, using biochemical oxygen demand (BOD) and chemical oxygen demand (COD) tests. BOD measures the potential of the pollutants present in the effluent to sustain bacteria which consume oxygen. The test attempts to represent the conditions likely to occur in a river as a result of the natural purification capacity of the water. COD measures the oxygen demand in the presence of a strong oxidizing agent, and is a measure of the total amount of oxygen required to stabilize the waste.

Domestic sewage

In addition to human fecal waste, domestic sewage contains detergents, other household chemicals and waste from food preparation. The volume of domestic sewage produced is similar to the volume of water supplied to an area,

Domestic sewage therefore enters rivers in three forms:

(a) As effluent from treatment works.

(b) Diluted with runoff in wet weather from overflows.

(c) Undiluted from old or poorly designed systems.

Discharges of all three types can be controlled by better design and management of sewerage systems.

Surface runoff

Runoff from urban surfaces contains pollutants derived from atmospheric deposition, street refuse, traffic emissions and urban erosion. Industrial site runoff can contain oils and toxic chemicals, and runoff from agricultural land can contain pesticides and fertilizers. Measured runoff quality is extremely variable and is influenced by many factors.

Table 2.4. Pollutant concentrations in runoff

No.	Pollutants	Highway runoff	Residential areas	Commercial areas	Industrial areas	Remark
1	Suspended solids (mg/l)	28 - 1178	112 - 1104	230 - 1894	34 – 374	
2	BOD (O_2/mgl)	12 - 32	7 - 56	5 - 17	8 – 12	
3	COD (O_2/mgl)	128 - 171	37 - 120	74 - 160	40 – 70	
4	Ammonia (N/mgl)	0.02 – 2.1	0.3 – 3.3	0.03 – 5.1	0.2 – 1.1	
5	Lead	0.15 – 2.9	0.09 – 0.44	0.1 – 0.4	0.6 – 1.2	

(Source: From Hall and Ellis (1985))

Industrial and agricultural discharges and spillages

Many industrial effluents are discharged, with consent, directly to sewers, where they can be treated with domestic sewage. At times of high flow, these effluents are spilled over combined sewer overflows. Industrial wastages can also enter rivers via sewerage systems following accidental spillage or deliberate illegal discharge. Industrial effluent quality varies with the nature of the discharger's business and the degree of treatment provided prior to discharge. Highly polluting effluents include food-processing wastes, which are rich in organic matte and exert a high oxygen demand, and metal-finishing effluents, which contain toxic metals and cyanides. In some cases, discharge of spilled wastes to rivers may be preferable to attempting to treat them at a sewage treatment works, where they can cause disruption of the biological treatment process, thus adding domestic sewage to the works effluent.

Pollution from agricultural activities is increasing in developed countries, and the environmental impact is often more severe than in cases of sewage or industrial pollution. Milk pollution, for example, can be 700 times more harmful than raw sewage. Agricultural wastes can enter drainage systems as a result of poor farming practice, accidental spillage and discharges to sewers. The most common sources of pollutants are silage liquor, pesticides, farm slurry and agricultural chemicals.

In-pipe deposits

Deposits of sediments in sewers originate from domestic sewage, urban and rural runoff and industrial and agricultural wastes. Although not a primary source of pollutants, deposits provide a reservoir of pollutants in sewers which can be eroded during high flows and spilled into rivers via combined sewer overflows. The erosion of deposits from combined systems by rising flows is probably one of the prime causes of a first foul flush in which peak pollutant concentrations occur before the peak discharge. This can produce gross pollution even in modest storms. Sediment deposits can also affect the hydraulic capacity of sewers, thus causing premature overflow to rivers from combined systems.

The problems of sediment in sewers can be reduced in new systems by designing them to be self-cleansing and by maintaining a minimum flow velocity often taken as 0.9- 0.75 ms-1 for small to large sewers (White, 1987). This requires provision of a sufficient gradient, or pumping, so that sediment does not have an opportunity to settle out. Some sediment accumulation is, however, inevitable and must be designed for.

Source control

Domestic foul drainage is one of the fundamental purposes of urban drainage and it is not practical to control this source other than to discourage the discharge of pollutants such as motor oil.

Reducing the quantity of storm water runoff by surface detention storage or infiltration areas will reduce the pollutant load. Care should be taken with infiltration that the polluted runoff 'cannot affect aquifers which are used for water supply. The pollutant load of the storm water may be reduced by road sweeping. Research has generally indicated that road sweeping is effective at removing coarse particles, not the very fine particles which are the most polluting. Surface water generally enters the drainage system through gully pots or catch pits. These are effective at trapping coarse particles which would cause hydraulic obstruction and can also trap oil. However the breakdown of the sediment retained in gullies can provide a reservoir of polluted water to be washed out at. The start of a storm exacerbates the first foul flush. To be of any benefit gullies need to be cleaned regularly.

Industrial pollutants should be controlled at source by pretreatment before discharge into the sewerage system. Allowing them to be discharged into the system can not only cause pollution by the operation of overflows, but can also affect the operation of sewage treatment works.

2.9 Storm water Management Practices and Guidelines

General

Storm water Management Practices are a series of practices or treatment methods that reduce the effects of storm water pollution and meet storm water management objectives for a given area. Effective storm water management is often achieved from a management systems approach rather than focusing on individual practices. That is, the pollutant control achievable from any management system is viewed as the sum of parts, taking into account the range of effectiveness associated with each single practice, the cost of each practice, and the resulting overall cost and effectiveness. Some individual practices may not be very effective alone but, in combination with others, may provide a key function in highly effective systems.

The selection and design of management practices must incorporate water quantity and water quality concerns. Storm water management practices that are considered for the control of urban storm water runoff are as follows:

- Source controls;
- on-site (lot-level) and conveyance system controls; and
- end-of-pipe controls

The minor and major (piped) systems should be designed for 1:5 and 1:100 year events, respectively. The minor systems consist of drainage works that transport flows from a catchment during minor rainstorms. The major systems consist of drainage routes that transport flow during major storm events. All of the municipalities should give considerations regarding mosquito control programs near any open storm water systems, such as wet ponds.

Regarding interconnection, no interconnection is permitted between sanitary and storm sewers and the discharge of sewage from sanitary sewers into storm sewers is not permitted. First flush is a common phenomenon encountered during first runoff from a storm and often it is contaminated. It is caused by the rapid mobilization of contaminants attached to fine sediments on impervious surfaces and by the flushing of catch basins and manholes. Sufficient storage requirements are recommended to reduce the effect of “first flush” in detention systems such as wet ponds, dry ponds and constructed wetlands.

Source Controls

Adoption of pollution prevention and source control practices minimize the level of pollutants entering the storm water systems. Source control is a simple concept, which can be cost effective and requires public participation. Source control measures include:

- pet waste collection;
- street cleaning;
- storm drain system cleaning;
- catch basin cleaning and
- Eliminating non-storm water discharges.

<u>Pet waste collection</u>, as a source control involves using a combination of education programs and compliance to encourage residents to clean up after their pets. The presence of pet waste in storm water runoff has a number of implications for urban stream water quality, with perhaps the greatest impact from fecal bacteria.

According to a recent research study, nonhuman waste represents a significant source of bacterial contamination in urban watersheds. These bacteria can pose health risks to humans and other animals and result in the spread of disease. Pet waste may also be a factor in the eutrophication of lakes. The release of nutrients from the decay of pet waste promotes weed and algae growth, limiting light penetration and the growth of aquatic vegetation. This situation, in turn, can reduce oxygen levels in the water, affecting fish and other aquatic organisms. Pet waste collection programs use pet awareness and education, signs and pet waste control ordinances to alert residents to the proper disposal techniques for pet droppings (Water Security Agency, 2014).

Street cleaning practices such as street sweeping on a regular basis minimizes pollutant level in storm water runoff and receiving waters. These cleaning practices are designed to remove from road and parking lot surfaces sediment debris and other pollutants that are a potential source of pollution impacting urban waterways. Street sweeping practice removes sediment buildup and large debris from curb gutters. The effectiveness of street sweeping in regard to reduction of pollutant level depends on factors such as frequency, time of year, type of sweeping equipment, rainfall intensity, length of time between rainfall events and type of road surface.

Storm drain systems need to be cleaned regularly. Routine cleaning reduces the amount of pollutants, trash and debris both in the storm drain system and in receiving waters. Clogged drains and storm drain inlets can cause the drains to overflow, leading to increased erosion. Benefits of cleaning include increased dissolved oxygen, reduced levels of bacteria and support of in-stream habitat. Areas with relatively flat grades or low flows should be given special attention because they rarely achieve high enough flows to flush themselves.

Catch basin cleaning is an efficient and cost effective method for preventing the transport of sediment and pollutant to receiving water bodies. Catch basins are chambers or sumps, usually built at the curb line, which allow the surface water runoff to enter the storm water conveyance system. Many catch basins have a low area below the invert of the outlet pipe intended to retain coarse sediment. By trapping sediment, catch basins prevent solids from clogging the storm sewer and being washed into receiving waters. Catch basins must be cleaned periodically to maintain their ability to trap sediment and consequently their ability to prevent flooding.

Pesticide management measures involve limiting the impact of pesticides on water quality by educating residents and businesses on alternatives to pesticide use, proper storage and on application techniques. The presence of pesticides in storm water runoff has a direct impact on the health of aquatic organisms and can present a threat to humans through contamination of drinking water supplies. The major source of pesticides to urban streams is home application of products designed to kill insects and weeds in the lawn and garden. Pesticide pollution prevention programs try to limit adverse impacts of insecticides and herbicides by providing information on alternative pest control techniques other than chemicals or explaining how to determine the correct dosages needed to manage pests.

One of the important source control measures is identifying and eliminating non-storm water discharges to storm sewers, which is cost-effective and improves the water quality of runoff.

Non-storm water discharges can include discharge of process water, air conditioner condensate, non-contact cooling water, vehicle wash water or sanitary wastes, and are typically the result of unauthorized connections of sanitary or process wastewater drains to storm sewers.

Environmental impact evaluations have shown that the elimination of non-storm water discharges is an effective management practice because such discharges may contain significant loading of pollutants.

On-site (Lot-level) and conveyance system controls

On-site (Lot-level) controls

On-site (Lot-level) controls are practices that reduce the quantity of storm water runoff and improve the water quality before the runoff reaches the conveyance system. These practices are applied at a single lot level or multiple lots in a small area.

End-of-pipe controls

End-of-pipe controls are the final treatment methods that are intended to reduce the pollutants and enhance the quality of storm water runoff before discharging into receiving waters. Although a number of end-of pipe controls are available for treating storm water runoff, selection of a suitable treatment depends on the site conditions, upstream runoff characteristics and requirements for treated water quality. End-of pipe controls are as follows:

- wet ponds;
- dry ponds;
- constructed wetlands;
- infiltration trench;
- infiltration basin;
- sand filters; and
- Oil/grit separators.

End-of-pipe controls, such as wet ponds or dry ponds should be designed for 1:100 year event with a safe overflow route so as to avoid flooding for large events.

Wet ponds

Wet detention ponds are storm water control structures designed to retain and treat the contaminated storm water runoff. Although there are several different versions of the wet pond design, the most common design is the extended detention wet pond where adequate storage is provided above the permanent pool in order to detain storm water runoff and provide settling. Wet ponds are among the most cost-effective and widely used storm water practices.

Dry ponds

Dry ponds are basins whose outlets have been designed to detain the storm water runoff for some minimum time (i.e. 24 hours) to allow particles and associated pollutants to settle. Unlike wet ponds, these facilities do not have a large permanent pool. Dry ponds have only moderate pollutant removal when compared to other treatment methods. Although dry ponds can be effective at removing some pollutants through settling, they are less effective at removing soluble pollutants because of the absence of a permanent pool. Dry ponds operating in a continuous or batch mode have been reported to be less effective at pollutant removal compared to wet ponds. Generally, dry ponds should be implemented if wet ponds cannot be implemented due to site or planning constraints.

Constructed wetlands

Constructed wetland is a suitable treatment method for storm water quality enhancement where a large area of land is available for construction. They require a large area of land because of their shallower depth (both in the permanent pool and active storage depth). Pollutant removal effectiveness and water quality enhancement in wetland systems are achieved through physical, chemical and biological processes.

Infiltration trench

Infiltration trench in this guideline refer to infiltration systems designed to collect, store and treat the storm water runoff from several lots as opposed to on-lot infiltration systems that are used for single lot application. An infiltration trench can be constructed at the ground surface to intercept overland flows or below ground as a component of a storm sewer system. These systems are suitable where limited land is available. However, the application of infiltration trench is limited because they provide marginal water quality control, but may be used as a secondary facility where the maintenance of groundwater recharge is a concern. They also can be used in conjunction with other practices, such as wet ponds, to provide water quality control and peak flow control. Infiltration trenches can be implemented for residential uses where soils should have an infiltration rate of ≥ 15 millimeters per hour.

Infiltration basin

Infiltration basins are above ground pond systems designed to collect, store and treat the storm water runoff. Water infiltrates through the basin and either recharges the groundwater or is collected by an underground perforated pipe system and discharges to a downstream outlet. The appearance of an infiltration basin is similar to that of wet ponds. Infiltration basins are suitable for residential land uses and not recommended for industrial/commercial areas where there is a high potential for groundwater contamination due to chemical spills and maintenance activities. Infiltration basin have a high rate of failure and the factors that contribute to the failure are poor site selection, poor design, large drainage area, inadequate pretreatment facilities and lack of maintenance.

Sand filters

Sand filters generally control storm water quality, providing very limited flow rate control. There are many forms of sand filters, among these surface and underground filters are the most commonly used. Sand filters are suitable for small drainage areas (less than or equal to five hectares). In general, sand filters are preferred over infiltration practices, such as infiltration trenches, when contamination of groundwater with *conventional pollutants* (Biochemical Oxygen Demand, suspended solids and fecal coliform) is of concern. Sand filters generally require less land than other practices such as ponds or wetlands. Sand filters can be effective storm water management practices and can achieve high removal rates for sediment, BOD and fecal coliform bacteria.

Oil/grit separators

Oil/grit separators consists a series of chambers to trap and retain oil and grit and/or sediment in the chambers. They are usually located below ground and often are used as spill controls, pretreatment devices or end-of-pipe controls as part of multi-component management practices for water quality control. Oil/grit separators are used for small drainage areas (< 2 hectares). They can be used for industrial and commercial areas, parking lots, automobile service station parking areas and airports that generate high hydrocarbon concentrations and where there is a high risk of spills. There are two types of oil/grit separators available: Three chamber oil/grit separator and By-pass oil/grit separator.

Detention ponds

Detention ponds or detention basins are temporary storage facilities that are ordinarily dry but are designed in such a manner that they are able to store storm water runoff for short periods of time. The captured storm water runoff either infiltrates into the underlying soil layers or, more usually, is drained into the downstream watercourse at a predetermined rate. This means that detention ponds are particularly effective at regulating the flow in the downstream watercourses and/or supplementary treatment systems. They are usually grass lined, but concrete lined ponds can be used if there are soil stability or land use issues. The use of detention ponds depends on the availability of adequate space.

Advantages

i) They are able to temporarily store large volumes of storm water thus attenuating downstream flood peaks;

ii) Detention ponds are relatively inexpensive to construct and easy to maintain;

iii) Detention ponds may serve multiple purposes during drier seasons, particularly as sports fields, play parks or commons.

Care should though be taken where storm water may be contaminated with sewage as this will pose health and environmental risks; and

iv) If managed regularly, detention ponds can add aesthetic value to adjoining residential properties as well as presenting fewer safety hazards than wet ponds due to the absence of a permanent pool of water.

Limitations

i) Detention ponds are not very good at removing dissolved pollutants and fine material;

ii) Detention ponds are generally not as effective in removing pathogens as constructed wetlands;

iii) Siltation can be a problem;

iv) The floors of detention ponds can become swampy for some time after major rainfall;

v) For best results, detention ponds should have a large plan area. This takes up valuable land;

vi) Detention ponds are not very suitable in areas with a relatively high water table, or where the soil is very coarse and there is a risk of groundwater contamination (Hobart City Council 2006, Taylor 2003).

Infiltration basins

Infiltration basins are very similar to detention ponds in design, construction and maintenance except that they do not ordinarily discharge into a downstream watercourse. Instead, storm water runoff is infiltrated into the ground where it recharges the underlying aquifers. The quality of the water is improved through filtration through the sand medium. This can be enhanced through the use of vegetation in the same manner as a bio retention device. They are usually designed to handle small rainfall events from catchment areas of less than 4 ha.

Retention ponds

Retention ponds, also referred to as ‘retention basins’, have a permanent pool of water in them (Debo & Reese, 2003; Mays 2001). They are generally formed through the construction of a dam wall (or walls) equipped with a weir outlet structure. The maximum storage capacity of retention ponds is larger than their permanent pond volume. Storm water coming into the pond is mixed with the permanent pond water and released over the weir at a reduced rate. Retention ponds are usually capable of handling relatively large quantities of storm water runoff (Woods-Ballard *et al.,* 2007). The permanent pond volume can be utilized as a source of water for various non-potable purposes.

Advantages

i) The incorporation of retention ponds into the natural landscape promotes biodiversity; they can also be used for recreational purposes where adequate supervision is available;

ii) Retention ponds generally have the capacity to remove a wide range of common storm water runoff pollutants;

iii) Retention ponds are one of the most cost effective SuDS options; and

iv) Storm water runoff that is captured in retention ponds can be reused for irrigation or secondary domestic purposes where the water quality is acceptable.

Limitations

i) The permanent open pool of water creates health and safety concerns and therefore requires social impact considerations at the design stage;

ii) If maintained infrequently or irregularly the permanent open pool of water could display unsightly floating debris and scum. Other nuisances include foul odours and mosquitoes;

iii) Retention ponds are normally restricted to sites with shallow slopes;

iv) Retention ponds require a base flow or the addition of supplementary water to maintain a specified permanent water line;

v) Retention ponds may attract birds, such as herons, whose faeces can cause an increase in phosphorous in the water; and

vi) Retention ponds are generally not as effective in removing pathogens as constructed wetlands.

Constructed wetlands

Wetlands generally refer to marshy areas of shallow water partially or completely covered in aquatic vegetation. They may be categorized into: natural, modified natural, or constructed wetlands. They can provide a vibrant habitat for fish, birds and other wildlife – potentially offering a sanctuary for rare and endangered species. Their aesthetic appeal encourages their recreational use. Constructed wetlands are man-made systems designed to mimic the natural systems in areas where they would not usually be found. They are most often to be found serving catchments larger than 10 ha, and are particularly useful in attenuating storm water flood peaks and 'polishing' the runoff from residential areas (Endicott & Walker, 2003). The most common storm water runoff pollutant treatment processes that occur in constructed wetlands are: sedimentation, fine particle filtration and biological nutrient and pathogen removal (Field & Sullivan, 2003; Parkinson & Mark, 2005). Wetlands cannot remove all pathogens. The percentage removal depends *inter alia* on the pollution concentration of the inflow, the rate of flow-through, the pollution saturation level of the wetland and the degree to which the pathogens clump or adhere to settleable particles.

2.10 Surface water

The drainage process in urban areas is different from that in rural areas. Because of the paved surfaces in urban areas, precipitation is drained immediately and the losses are minimal in comparison with those in rural areas. Urban surface drainage has two functions: the removal of drainage water and the temporary storage of drainage water. In designing the system one should take into account the storage required and the discharge capacity of the drains.

If rainfall can be drained immediately, the waterways and the structural works in the area will be designed based on the drainage capacity. In general, this is determined using the Chezy or Manning-Strickler formula.

In general, the following criteria must be considered in the design of open waterways in urban areas:

- Sufficient land reclamation.
- The maximum water level rise for a given rainstorm with a given recurrence time.
- Ease of maintenance.
- Ease of cleaning (to control water quality).
- Minimum ground use.
- Minimum number of structural control works.

2.11 Surface drainage from roads

One of the main problems in urban areas is the removal of water from road surfaces. This is essential, since excess surface water can lead to the loss of adhesion between vehicle tyres and the road surface and also to a spray hazard for all road users, including pedestrians. As in the case of storm sewers, design of facilities to deal with surface water is dependent on a hydrological assessment of the amount of water to be disposed of and a hydraulic assessment of the way in which the water moves towards and ultimately in the channels, pipes, etc., carrying it away from the area.

Frequently surface water is discharged into a sewer system, either combined or separate. What has yet to be considered is the way in which the water is collected from the road surface. There are essentially two collection systems, one in which water is allowed to flow over the edge of the road pavement into an open drain or ditch, and the other in which water flows in a channel formed by a raised curb, verge or other boundary and discharges into gullies or outlets placed at regular intervals. In temperate climates and in large conurbations the latter system is more usual.

In order that water may flow off the road pavement, a transverse gradient is required, and then to allow the water to flow towards an outlet a longitudinal gradient is required. When the road is kerbed the result is to produce a triangular channel sloping towards the outlet. Problems arise when for traffic engineering reasons shallow gradients are required, leading to loss of hydraulic efficiency. One solution is to produce 'false channel profiles' by creating artificial gradients in the curbside channels by raising and lowering these in relation to the overall longitudinal gradient. For drainage design purposes roads are classified according to their longitudinal gradients, the categories being longitudinal gradients greater than 0.5% and less than 0.2% with a transition zone between 0.5 and 0.2%. These are summarized as follows.

<u>Longitudinal gradients greater than 0.5%</u> Consider rain of intensity I mm h- 1 falling on a section of road surface B m wide, with transverse gradient C (expressed as a fraction), longitudinal gradient S (as a fraction) and draining into a triangular curbside channel. In order to limit the width, W(m), of flow in the channel, outlets or gullies have to be placed at regular intervals of Jm. The outlet spacing may be obtained from:-

J = 0.315K/nBI W8/3C5/3S1/2

where K is a constant equal to 1 when meter units are used throughout, and n is Manning's roughness coefficient, often taken as 0.01 for road surfaces. Introducing a gulley or outlet efficiency factor, E%, usually of the order of 90% for gullies set into the road surface, then

J = 0.315K/nBI W8/3C5/3S1/2E/100

2.12 Storm Water Management Facilities Design Criteria

Types of Drainage Data (AASHTO 2007)

- watershed boundaries and sizes;
- existing drainage patterns;
- complete description of potential outfall locations;
- general description of ground cover;
- land use (present and expected future);
- flood histories and high water mark elevations;
- age and description of existing drainage facilities (size, shape, material, invert elev., condition);
- design data of existing drainage systems;
- existing right-of-way;
- performance histories of existing facilities;
- utility locations (plan and elevation) and descriptions;
- soil conditions;
- local ordinances;
- Topographic data; and
- Highway geometric data (pavement cross slope, pavement width, longitudinal gutter grade, etc.)

The basic information necessary for the design of urban storm water management facilities requires investigations of the following areas: topography, geography, water table, geology, water source, soil information, environmental factors, physical constraints, land use, zoning restrictions, and other governmental regulations.

Site analysis is a thorough review of existing information on the site and its surrounding area. Additional mapping or data may be required to prepare a proper design and contract documents.

Topography

All site features that could influence the storm water management facility location, installation, and operation must be considered in the design phase. Topographic mapping of the drainage area documents the runoff paths and contributory areas. A general topographic map of a scale of 1:1,200 or 1:2,400 of the project site and its surrounding area is required in the preliminary design stage. Surface drainage courses should be identified, particularly with focus on locations where concentrated flows (swales and streams) enter and exit the project work area, right-of-way, or property. A detailed topographic map at a scale of 1-inch equaling 50 feet or less (1:600 or less) depicting planimetric features such as trees, ponds, ditches and other existing drainage facilities, culverts and catch basins, buildings, roads, walks, overhead utilities, and surface components of underground utilities is necessary to develop and complete the design. Elevation point data should be accurate to within 0.5 feet (0.15 m) on disturbed areas and 0.2 feet (0.06 m) on hard surfaces. Contour intervals should be no greater than 2 feet (0.6 m). Additional research of “as-built” underground utility records may be required to avoid conflicts. All site mapping and critical utilities should be field checked prior to use.

Geography

The design engineer should be sensitive to particular geographic constraints that influence site conditions. Some of these constraints may include coastal areas subject to tidal and storm surge conditions, Karst topography that form discontinuous drainage patterns, floodplains, mining areas or areas subject to earth movement (earthquake, subsidence, mud slides, permafrost, etc.), or special preservation areas and historic sites. Any of these constraints should be identified prior to beginning design.

Water table

The site may require an evaluation of the underlying water table early in the design phase. The design engineer must know the type, the depth below the surface, and conditions of hydrostatic heads of the water table. Information related to water table fluctuation throughout the year must be evaluated. An understanding of the potential impact of water table response from rainfall, nearby well drawdown, and direction of flow may be appropriate if the water table will be in the proximity of a proposed facility.

Geology

The underlying rock and soil strata may affect the design of the storm water management facilities in several ways. The design engineer should be aware of the potential impacts of foundation seepage, slope stability of cut slopes, settlement, impervious layers, high shrink-swell potential clays, or unstable organic layers.

Water Source

In most cases, concentrated flows (swales and streams) entering the project site from major upstream (off-site) drainage areas are diverted past the storm water management facility. Large off-site inflow will tend to reduce the effectiveness of both water quantity and quality controls and result in larger and more expensive control structures. An exception to this is the regional storm water management facility that is designed to handle high volumes of inflow.

Soil information

Soil type and properties will affect many aspects of design including potential for underground disposal with infiltration systems, embankment material selection, structure foundation support, suitability of permanent storage, and surface stabilization.

Soil classification

Information on soil classification can be presented in accordance with the unified soil classification system, like AASHTO or our national equivalent institute that is endowed with classification of soil to codify and determine vegetation support and wetland delineation. These classification systems are used to assist the design engineer in estimating engineering properties such as permeability, shrink-swell potential, densities, and bearing capacity.

In addition, some of these classification systems offer guides in engineering uses including suitability for embankments, core or cutoff trenches, road subgrade, filter material, pond liners, and others.

Permeability

Permeability of soil is important for the design of infiltration systems, filter systems, and embankments. In situ permeability tests are most useful for the design of infiltration systems. Laboratory tests on retrieved samples or empirical data based on grain size and soil classification are used for newly placed material and may be modified by suitable safety factors to account for variations between test and in-place material behavior.

Strata and layers

Identification of variation of surface strata may be important to predict foundation seepage, support, or stability.

Soil/Water chemistry

Salinity, corrosive, and pH properties may affect the material selection for outfall pipes and underground structures. Local conditions may suggest the use of coatings for metallic pipe, metallic fixtures on structures, concrete in contact with soil or water, and concrete reinforcement.

Temperature

Frost depth and freeze-thaw conditions may cause soil movement and structure or pipe damage. Adequate design allowances and installation depth should be provided in areas where conditions are severe. In general, soils that have a high percentage of silt are most susceptible to frost heaving.

Soil testing

Adequate soil data are necessary in the design of storm water management facilities. Soil data may be available from prior tests. However, most projects will require soil borings and laboratory tests to determine engineering properties and classifications. Standard penetration borings may be supplemented with sample recovery, grain size analysis, Atterberg limits, permeability, and moisture-density laboratory tests. Embankment and foundation design may require shear strength and California Bearing Ratio (CBR) tests. Often the soil data will have a significant influence on the design and cost of construction. Minimizing soil borings or laboratory testing to save design cost is generally not a prudent engineering decision.

Environmental factors

Some of the major environmental considerations in the design of storm water management facilities are listed below. These factors must be considered during design to prevent adverse environmental impacts to adjacent land, residents, and environmentally sensitive ecosystems.

Water quality

Improvement in runoff water quality is often the intent of the storm water management facility. Generally site-specific water quality data for urban runoff is difficult to obtain due to seasonal and rainfall event variability. Many systems or facility types are designed using empirical criteria such as a theoretical percent pollutant reduction based on retention time or filter depth. Special consideration may be given to oil-laden pavement runoff in cases such as parking lots, trucking facilities, or high-volume roads. In these cases, oil water separators and filter systems may be necessary. Also, suspended sediment may be reduced with the use of vegetation strips, structure sumps, or traps. Storm water management facilities that serve chemical facilities or hazardous waste storage sites require careful attention to containment functions and security.

Flooding

Storm water management facilities in areas subjected to flooding require consideration of hydraulic effects due to high tail water for outlets, embankment stability for drawdown on both faces, additional storage for interior drainage, and outlet control flap or sluice gates.

Wetlands

Additional consideration is required for the ecological-environmental aspects of the site when applying artificial drainage to a wetland area. Most wetlands are environmentally sensitive ecosystems. The maintenance of wetlands and its ecosystems is important. Many wetlands filter natural and man-made pollutants. Changes in the quality and/or quantity of surface waters entering a wetland can adversely affect this sensitive filtering process and may cause detrimental effects to flora and fauna. Local, state, and federal governments classify wetlands. Any project associated with a wetland will most likely require permits from local, state, and/or the federal government.

Principal or Primary aquifers

These aquifers are often tapped as a main water source. The intended use of this water determines the necessity and amount of protection required. If a possibility exists for contamination of the aquifer, mitigation measures must be taken to prevent such contamination. Other design alternatives including relocation of the system or a treatment and monitoring program of the discharge may be necessary to remove the contamination potential.

Hydrology

Hydrology describes the movement of water. Development modifies the natural hydrologic cycle. It has become a valid concern in recent years. The development of surface drainage systems should follow the natural hydrologic cycle as closely as possible. For example, if the natural cycle exists as rainfall percolating into groundwater, then joining surface watercourses, the man-made cycle should parallel this movement. Not all hydrologic cycles are this simple and thus easily paralleled. It is important to consider the natural or existing hydrologic cycle of the site in the design.

Physical constraints

Most urban settings have constraints related to existing or planned utilities that must be considered in the design of storm water management systems. Compatibility of the proposed facility with existing drain systems is critical to any layout. The location of utilities may require special consideration in the design phase to accommodate storm drains, future development, and master planning.

2.13 Hydraulic structures

Numerous hydraulic structures are utilized in urban drainage systems. Each type produces a restriction to streamflow that can be defined by a unique head loss relationship or calculation procedure. These relationships and procedures have been derived from hydraulic theory and empirical data. These hydraulic structures include:

- Storm sewer inlets
- Outlet structures
- Culverts
- Spillways
- Energy dissipaters
- Bridges
- Drop structures

When these structures are added to the drainage system, associated hydraulic losses must be added to the stream profile. For steady-state flow conditions, the head loss relationships and procedures that have been developed for these structures can be used to estimate the influence of the structure on the upstream or downstream water surface elevation.

The initial design criteria are usually hydrological. The rainfall intensity, the quantity of surplus water or the magnitude of the river flood provides the first consideration. From the extreme value analysis, the chances of occurrence of a critical quantity and its estimated return period or average recurrence interval have been evaluated. For minor drainage works, standard criteria have often been accepted as general practice, but for expensive flood protection schemes more rigorous procedures are usually required.

Open channels

Open channels are variously called ditches, dykes, cuts, drains or canals and can have a variety of functions in addition to land drainage. However, none of this is of any significance in terms of design criteria for land drainage works and the term 'ditch' is used here to represent all open channels. Ditches can be used for the following drainage purposes:

- To act directly as land drains in surface aquicludes.
- To control the groundwater table in surface aquifers.
- To intercept surface flow, interflow or groundwater flow.
- To collect water from underdrainage systems.
- To carry water to the outlet channel.
- To act as reservoirs for drainage pumps.

The merits of these various functions can be discussed in turn, but it is necessary, first, to consider the general characteristics of open channels. Ditches have the advantage of allowing easy entry of surface flow or interflow water into the channel. They can be very effective even with slight gradients and have a very good overload capacity to cope with storm conditions. The open channel permits easy access to the outlets of associated underdrainage systems for maintenance purposes. They also have some disadvantages. Open channels permanently occupy land and restrict field traffic. They often require protective/safety fencing and crossing points, while the channel efficiency can deteriorate rapidly as weeds grow, silt accumulates and obstructions occur. Regular maintenance work is always required to keep the channel clear and free-flowing.

Underdrainage

Underdrainage is the basis of the great majority of field drainage works and involves the creation of permanent drainage channels by means of buried pipes. The pipes are usually either short-length, butt-jointed, clayware tiles which permit water entry at the joints, or continuous-length, perforated and flexible plastic piping. For most projects, one type or the other will be used exclusively, based on customer/contractor preference, but both types are effective if installed correctly. For larger capacity drains the normal range of cast concrete or fiber cement pipes can be used, and, where the pipes need not be sealed and will not be under pressure in use, it is quite satisfactory to use sound, out-grade sewerage pipes.

The buried channels of underdrainage can remove excess water without occupying land. They do not restrict field traffic and are protected from the general accumulation of rubbish. There is no weed growth in the channel, and the system can remain effective for many years with little need for maintenance. However, buried channels are not immune from siltation and blockage, and where maintenance is required it can be expensive and troublesome, sometimes requiring considerable remedial attention or even complete replacement of the whole system. Installation costs of new systems are more expensive than for an equivalent open-channel system. Pipes have very little overload capacity and, without special provision for regular maintenance, they require a greater gradient than open channels to remain effective. The most common limiting factor, however, is that excess water is prevented from flowing into the drainage channel by a poorly permeable soil profile.

Storm water inlets

Storm water inlet structures include headwalls, curb inlets, grated catch basins, and line drains (slotted drain and precast polymer concrete trench drain inlets). These structures can be flush with the ground or road surface, or depressed below grade to form a sump that increases capacity. They regulate how storm water can enter a conveyance system. The proper design of inlet structures is important to control gutter and sheet flows, thereby limiting hydroplaning and flooding. Storm water inlet structures often act as hydraulic controls that regulate how storm water enters the conveyance system. As such, hydraulic calculations to determine their capacity can often be independent of the hydraulic losses in the conveyance system. The conveyance system design should always be checked to ensure that downstream tail water levels at all inlets do not influence their capacity. If tail water is elevated, the appropriate inlet capacity reduction factor should be applied. Design of the inlet structure begins with an evaluation of how storm water is conveyed toward the inlet. The allowable gutter flow can be estimated with the following equation (ASCE/EWRI 45-05 (Standard guidelines for the design of urban storm water systems)):

$$\mathbf{Q = (c/n)T^{2.67}S_T^{1.67}S_L^{0.5}}$$

where

Q gutter flow, m^3 s

c constant, (0.56) 0.375

n Manning's roughness coefficient

T allowable spread m

ST transverse slope m/ m

SL longitudinal slope m/ m

This equation is derived from Manning Equation. *T*, *ST* and *SL* are the reciprocal of the street cross slope. Selection of the number, location, and size of inlets is based on the magnitude of the design flow. Curb inlets are considered to be relatively inefficient.

Culverts

Culverts are relatively short conduits typically used for road crossings of small to moderate-sized streams. Culverts are available in a variety of shapes and materials, some exceeding 200-foot (65.6 m) spans. Culverts can be prefabricated or custom-made in the field. Culvert hydraulic analysis has been refined to several widely used procedures due to the abundant use and type of conduit. Culverts cause an abrupt change in streamflow characteristics. The acceleration of flow that occurs causes head losses. Flow within the culvert can range from tranquil to rapid, and the structure can flow either partially full or under pressure. Hydraulic analysis of culverts requires consideration of tail water conditions, friction losses related to the culvert material and flow character, inlet and outlet losses, and minor losses within the culvert due to bends or other streamflow perturbations.

In general, one or a combination of the following controls the elevation of flow approaching a culvert:

• Critical depth control at inlet

• Tail water depth control

• Culvert entrance or barrel geometry

Peak discharge through the culvert is estimated by application of the continuity equation and the energy equation between the approach channel and a section within the culvert. When critical depth controls at the culvert entrance, culvert capacity is a function of entrance configuration and the change in velocity head at the entrance. Downstream culvert features such as barrel friction and tail water do not affect the capacity for this case.

Pipe and culvert structural requirements

Pipe can be broadly classified as either flexible or rigid. While both types work in concert with the backfill material surrounding them to support loads, the way the pipe is designed to respond to those loads differs.

Rigid pipe is sometimes classified as pipe that cannot deflect more than 2% without structural distress. Clay and concrete (reinforced and non-reinforced) are common examples. Rigid pipe transmits most of the vertical load through the pipe wall into the bedding so that proper design includes ensuring a combination of adequate wall strength and bedding and backfill conditions. Clay and concrete pipe are available in several standard strengths that, along with proper backfill, accommodate most installations.

Flexible pipe can move, or deflect, under loads without damage. Deflection allows the load to be transferred to and carried by the backfill. Examples of flexible pipe are corrugated metal, high-density polyethylene (HDPE), and polyvinyl chloride (PVC) products. Design procedures include a consideration of both pipe and soil strength.

Concrete pipe

Concrete pipe design

There are two types of concrete pipe design methods: the Direct Design Method and the Indirect Design Method. Both methods may be used for either reinforced or non-reinforced pipe. From the loads on the pipe, the <u>Direct Design Method</u> determines the moment, thrust, and shear stresses in the pipe, which are then used to determine the required reinforcement areas. The <u>Indirect Design Method</u> because of its simplification is used most often by designers. With this method, the loads on the pipe are calculated in the same way you would calculate the loads using the Direct Design Method. However, the earth pressures and their distribution around the pipe, and the resulting moments, shears, and thrusts are not calculated. Instead, the total field load on the pipe is related to the three-edge bearing test load on the pipe through the use of bedding factors.

2.14 Design of Drainage Systems

In order to provide hydrological criteria for the design of drainage systems, rainfall-runoff calculations are of great importance. One of the main requirements is obviously an accurate figure for precipitation. Rainfall data should be collected and further processed in such a way that they can be used for further calculations. Rainfall data themselves are of no value; what matters in drainage design is the amount of runoff that results from precipitation. Finally, using hydraulics, the appropriate size of the conduit has to be chosen. Flood estimation methods that may be applied to the design of storm water drainage systems can be divided into two broad categories: those which produce only an estimate of the peak flow rate and more comprehensive approaches that also provide the shape of the runoff hydrograph.

Precipitation

Two different kinds of rainfall data can be used for the design of storm sewers (Arnell, 1982):

(I) Design storms estimated from intensity-duration-frequency *(1-D-F)* relationships or from historical rainfall data. A design storm can be defined as a rainfall which is developed for a certain design return period, and the discharge value which is calculated by means of the storm is said to obtain the same return period as the storm.

(II) Historical storms or time series generated by statistical methods are run through a runoff model, and the statistical analysis is applied to the simulated flow values to determine the flow value coupled with the design return period.

In an I-D-F curve, rainfall intensities *(/)* for certain return periods are plotted against given durations (D). The return period of an event is the period during which the event is equaled or exceeded only once on the average. The greater the depth of rainfall, the shorter in general the length of time it continues. The development of 1-D-F relationships requires statistical analysis of data from one or several rainfall stations.

Losses and surface runoff

In storm sewer design, input flows are difficult to predict with a great deal of confidence. It is stressed, however, that dimensioning sewers and storage facilities on standards that are derived directly from precipitation data will lead to a significant over-dimensioning: the rainfall-runoff process is not to be neglected in the design process (Van de Ven, 1989b).

Flow in pipes

The rate of change of discharge in a drainage system is usually sufficiently slow to treat the flow as steady when calculating pipe sizes (kinematic wave approximation). Several flow formulae are available to determine flow and the size of pipe required. They have in common the fact that they relate capacity, hydraulic gradients, coefficients of friction and pipe size. Some basic equations for the flow in pipes are:

Manning-Strickler: $\mathbf{v=k_mR^{2/3}I^{1/2}}$

de Chezy: $\mathbf{v\text{-}CR^{1/2}I^{1/2}}$

Colebrook-White: $\mathbf{1/\sqrt{\lambda}=-2\log(1/0.4Re\sqrt{\lambda}+k/3.7D)}$

where v is the mean flow velocity (m s^{-1}),

I is the gradient, i.e. friction loss per unit length,

R is hydraulic radius = area/wetted perimeter (m) (for circular pipes counts R =

$1/4\pi D^2/\pi D$ = 1/4D),

D is the pipe diameter (m),

km is the roughness coefficient of Manning (m $^{1/3}s^{-1}$),

C is the roughness coefficient of de Chezy (m ^{112} $s^{-1\ 1}$),

λ is the dimensionless friction coefficient, *k* is the roughness coefficient (m) and

Re is the Reynolds number for full bore flow [Re= *vD/v;* where v =kinematic velocity (m2s-I)].

(Note: The Colebrook-White equation may be considered as the most up-to-date one, as it describes turbulent as well as laminar flow.)

The friction loss in a circular conduit can be calculated using the Darcy-Weisbach formula, which is:

$$\mathbf{z=\lambda\ Lv^2/D2_g}$$

where *z* is the friction loss (m), *L* is the length of the conduit (m) and *g* is the gravitational acceleration ($m\ s^{-2}$).

The rational method

Several methods have been employed by engineers to determine the sizing requirements for storm sewers. The most popular is the rational method. The rational formula is:

$$\mathbf{Q=CiA}$$

where *Q* is the design peak discharge ($m^3 s^{-1}$), *C* is a dimensionless runoff coefficient, i is the constant (net) rainfall intensity (m s- 1), lasting for a critical period of time tc, tc is the time of concentration (s) and *A* is the size of the drainage area (m^2).

The time-area method.

The inability of the rational method to deal with catchment areas in which the rate of increase in contributing area is variable led to the introduction of design methods based upon the use of the time-area diagram. During time, the area contributing to the discharge increases. First, the contributing area increases for the time of concentration

T1. Somewhat later, the second catchment will start contributing. Hence the area will increase between T3 and *T2* +T3 at that moment the area contributing is at its maximum.

Using time-area diagrams, the rational method may provide quite useful results, even when dealing with variable contributing areas. It is noted that more sophisticated, so-called tangent, methods have been derived from the time-area method. However, these methods show problems in their estimation of peak runoff rates and have now largely been abandoned.

Typical storm methods.

These methods differ from the time-area method only in that the variation of rainfall intensity with time (i.e. the storm profile) is included. This approach generally assumes an arbitrary shape of storm profile, constructed from the *1- D- F* relationship for a given frequency of occurrence.

The unit hydrograph.

The methods discussed above are mainly directed towards the estimation of peak flow. For certain problems, such as design criteria for pipes and structures, this may be sufficient.

However, for many purposes it is essential to know the distribution of the runoff volume in time, in order to assess peak discharge, time lag and runoff duration. The time-area method forms the first attempt in estimating the whole runoff hydrograph. A more sophisticated approximation is the unit hydrograph, which may be defined as the hydrograph of direct runoff, resulting from a unit depth of effective rainfall generated uniformly over the catchment area at a constant rate during a specified period of time.

Hydrological routing.

Flood-routing methods are used to predict the temporal and spatial variations of flood waves through the system. The rate of change of storage (S) can be written as the balance between inflow (/) and outflow (0) (the continuity equation):

$$dS/dt = I - 0$$

Considering a lumped storage approach, this equation can be generalized to a finite-difference equation for two points in time. An easy method of performing hydrological routing is reservoir routing, in which the storage is only related to outflow.

Hydraulic routing.

Hydraulic routing is more complex and accurate than hydrological routing and is based on the solution of the continuity equation and the momentum equation for unsteady flow in open conduits. Three different levels of hydraulic descriptions can be distinguished, incorporating different terms of the equation of Saint Venant:

Continuity equation: $\partial Q/\partial x + \partial A/\partial t = 0$

Momentum equation: $\partial Q/\partial t + \partial/\partial x\_(^{\beta}Q^2/A) + gA\partial h/\partial x + gAI_t = gAl_0$

$\partial Q/\partial t$ - Full dynamic wave approximation (Saint Venant equations)

$gA\partial h/\partial x$ – Diffusion (non-inertia) approximation

gAI_t – Kinematic wave approximation

where Q is the flow rate (m ^{3} s^{-I}), A is the cross-sectional area (m ^{2}), h is the flow depth (m), g is the gravitational acceleration (m s^{-2}), x is the longitudinal axis (m), t is time (s), $^{\beta}$ is the velocity distribution coefficient (-):

$^{\beta}$= $\mathbf{A/Q2A\int u^2 dA}$; where $u$is the flow velocity (m s^{-1})

I_0 is the bottom slope (-) and I_t *is* the friction slope (-).

Computer models.

In the last decade, many computer packages have become available for runoff calculations and urban drainage design. A distinction can be made between design methods and simulation methods. The former are used in designing new systems and are based on one or more of the standard methods described above. Since computer runs are fast, it is possible to calculate various options within a short time. Simulation models are used for analyzing the performance of existing systems or as a checking procedure on the hydraulic performance of new systems. Some models are capable of handling water quality features. In general much attention is being paid to the development of suitable numerical techniques to calculate pollutant transport; however, up until now, these efforts have not yet resulted in accurate models.

- The Wallingford procedure (WASSP).
- MicroWASSP:
- WALLRUS, the international version of MicroWASSP.
- MicroRAT, the spreadsheet implementation of the modified rational method with storage pond design.
- SPIDA, the simulation model for looped networks.
- MOSQITO, the water quality sub model.
- NEMOSYS, the graphics-based network modelling system.
- GURVIL, the graphics presentation program.
- MOUSE. (modelling of urban sewer systems)

2.15 Operation, maintenance and performance

In the past, operation and maintenance (O & M) of urban drainage systems has often been inadequate. The temptation has been to assume that if there were no immediate problems, there was no need to spend money. Yet, drainage systems corrode, erode, clog, collapse and ultimately deteriorate to the point of failure and beyond. Maintenance is needed to maintain the operational function of the system and to extend its working life.

Maintenance strategies

There are several reasons for the comprehensive maintenance of a sewer system.

<u>Public health</u>

Maintenance of public health is paramount and the continuing good functioning of the system can help to achieve it. In addition, the system itself should not cause nuisance or a health hazard to either its users or its operators.

<u>Asset management</u>

All systems were costly to construct and would be even more costly to replace. High priority must, therefore, be given to maintaining the physical integrity of the assets. A primary function of maintenance is to preserve the as-built hydraulic capacity of the system. This will minimize the possibility of wastewater backing-up into properties or widespread surface flooding. This can be done by cleaning and ensuring, as far as is practicable, that the system is watertight.

<u>Minimize pollution</u>

All combined and storm sewer systems have discharge points to the environment that come into operation periodically. Maintenance has a role in reducing the frequency of operation as far as possible, and in avoiding conditions in the system that cause build-up of pollutants.

Minimize disruption

The privatized water industry is judged by its customers on the efficiency with which it deals with operation and maintenance. Disruption to the general public should be minimized. Various degrees of sophistication can be built into maintenance strategies, but there are two main categories: reactive and planned

Reactive maintenance

In reactive maintenance, problems are dealt with on a corrective basis as they arise (i.e. after failure): the so-called ‘firefighting’ approach. This approach will always be required to a certain extent, as problems and emergencies are bound to occur from time-to-time in every urban drainage system. However, reactive maintenance cannot reduce the number of system failures. To achieve this, a planned approach is needed.

Planned maintenance

In planned maintenance, potential problems are dealt with prior to failure. Unlike reactive maintenance, planned maintenance is proactive and has the objective of reducing the frequency or risk of failure. Central to planned maintenance is a comprehensive inspection program and analysis of existing data. Planned maintenance is not the same as routine maintenance (operations at standard intervals, regardless of need), but involves identifying elements that require maintenance and then determining the optimum frequency of attention.

Operational functions

The major O & M functions are

- location and inspection
- cleaning and blockage clearance
- chemical dosing
- fabric rehabilitation – repair, renovation or replacement.

Finally, it should be noted that maintenance of sewer networks holds some specific challenges, even when compared with other industries. These include:

- geographical size of networks (e.g. dispersion and length of pipework)
- physical size of assets (e.g. access, non-man entry)
- aggressive environment (e.g. hazardous gases).

The main applications of sewer location and inspection are:

- periodic inspection to assess the condition of existing sewers (planned maintenance)
- crisis inspection to investigate emergency conditions or the cause of repeated problems along a particular sewer length (reactive maintenance)
- inspection of workmanship and structural condition of new sewers

2.16 Sewer cleaning techniques

Sewer cleaning is carried out:

- proactively, to remove sediment in order to restore hydraulic capacity and limit pollutant accumulation
- reactively, to deal with blockages or offensive odours
- to permit sewer inspection

- to aid sewer repair/renovation. Monitoring a sewer's condition is to carry out a series of inspections at given intervals. The level of inspection chosen will reflect an attempt to balance the risks with the consequences of failure.

Common Problems

Blockages

This are defined as full or partial restrictions within the sewer and are most commonly found in smaller diameter pipes. A blockage is normally associated with a system defect (e.g., displaced joint, severe change of direction). The effect of a blockage ranges from partial loss of capacity to complete stoppage.

Sedimentation

Sediment is defined as any settleable particulate material that may, under certain conditions, form bed deposits in sewers and associated hydraulic structures. It is normally associated with large, flat sewers. Sedimentation rarely completely chokes the pipe, but can still have a significant impact on capacity.

Grease/scale

Solidified grease is often associated with non-domestic properties, restaurants being particular culprits. High temperature dishwashers often move the grease from the premises, only for it to cool and solidify further downstream causing loss of hydraulic capacity. Wall scale or encrustation can also cause similar problems.

Tree roots

Sewers are susceptible to intrusion of tree roots, which seek out moist conditions. The roots themselves are a nuisance, both in retarding the flow but also in initiating further blockage with larger solids.

Intruding laterals

Intruding laterals or other connections are common as a result of poor construction practice. The intrusion reduces the cross-sectional area causing the same problems as tree roots. A number of cleaning techniques and methods are in use, depending particularly on location and severity, including rodding, winching, jetting, flushing and hand excavation. A combination of more than one method may well be used in any particular locality.

2.17 Drainage Policy

The national drainage policy clearly stipulates that:

a) The overall policy goal is to improve and enhance the health, safety and quality of life of the urban and hinterland population and enhance the environment on a sustainable basis.

b) Storm water is a component of the total water resources of an area and should not be casually discarded but rather, where feasible, should be used to replenish that resource. In many instances, storm water problems signal either misuse of a resource or unwise land activity.

c) Development of storm water drainage system is not possible in isolation from other infrastructure and environmental sectors. Coordination is necessary between different departments, government and other stakeholders and planning should take cognizance of processes such as integration.

d) Storm water drainage planning, design and management activities should ensure the participation of the people and other stakeholders at all levels.

e) Environmental considerations such as soil erosion and sedimentation must also be taken in to account in designing and construction of drainages.

CHAPTER THREE

3. MATERIALS AND METHODS

The scope of the research is geographically limited to Addis Ababa, CMC area particularly on the drainage structure of the trunk road that bisects Bole and Yeka sub-cities (Kifleketemas).

Since topography of the area is sloping towards south of the city, the stated drainage channels are subjected to accommodate large runoff from the adjacent elevated villages. Moreover, elevation of the road way itself is sloping gently down along the course hence; huge concentration of pavement runoff is directed to the same channel.

It is also apparent that the drainages overflow their channels and inundate the roadway and villages along the corridor and cause disruption of traffic movement and pose safety & health hazard to residents living around the area. Thus, to realistically assess the cause and consequences of drainage problems, efforts were made to observe, review documents and acquire information through survey from all offices that have similar dealings on design, policy and network of drainage structures as well as residents living along the route.

Experts in different authority levels working in the selected offices have responded to the questionnaire and gratefully many residents also gave their responses in time.

3.1 Data Collection

Three approaches were adopted to collect data.

1: Determine the type of data required for the selected research work

- Identify the issues to be considered

- ➢ Identify the type and accuracy of data required.

2: Identify the possible sources of data

- ✓ Identify the primary and secondary data
  - ‘Primary data’ may be collected from personal interviews, public discussions, field observation/site investigation, and completed questionnaires. Field investigations are generally necessary to determine drainage areas, identify pertinent features, survey channel sections, bridge and culvert crossings, etc.
  - ‘Secondary data’ include: published and unpublished data, and local agency files.
- ✓ Identify the possible sources of these data
  - There are limited potential sources of data typically available for storm water drainage design projects

3: Prepare data collection formats

- ❖ Determine the methods/instruments of data collection
- ❖ Prepare checklists
- ❖ Design questionnaire

There are many ways to categorize the types of data needed. Some data are continuous while others are discreet or binary (yes or no) data. Some are manmade while others are natural. Involvement of the relevant stakeholders during data collection is thus necessary.

Method

Method of data collection depends on the type of data to be collected. This research, particularly, adopted: Questionnaire, field survey/site investigation, observation (using topographic maps of the town and the size of the watershed), interviews, photographs, public discussions, etc.

The main Data was collected through questionnaire, interview and physical visit of sector offices, document review and observation. Six (6) offices (Addis Ababa City Road Authority, Addis Ababa Municipality, Addis Ababa light Railway enterprise, office of Master plan, Department of water supply & Sewerage and Ministry of construction) that have direct and indirect dealing with storm runoff drainage were contacted and given the questionnaire while residents living around the corridor of the study area were also contacted. 40 questionnaires were given out to respondents and only 29 were returned. The response rate is 72.5%. The data was then cleaned, sorted and shaped for subsequent evaluation and analysis.

Microsoft excel is used to clean, shape and sort the collected data.

3.2 Data Evaluation

The main reason for analyzing the data is to draw all of the various pieces of collected information together, and to fit them into a comprehensive and accurate representation of the hydrologic and hydraulic characteristics of a particular site. Evaluation is used to ascertain whether the data contains inconsistencies or other unexplained anomalies which might lead to erroneous calculations or results. Once the data is collected and sorted, it was compiled in a usable format for subsequent analysis.

3.3 Data Analysis

Data Analysis, on the other hand, is through; Wrangling, cleansing, and shaping data (data scraping), using Excel's analysis tool pack, utilizing multivariate statistics and other relevant techniques. On this analysis, it was tried to identify the major characteristics defining the water shed, examine the drainage patterns and analyze the land and water use.

Methods

- Use of maps;
- Use of simple mathematical expressions such as percentages, averages and slope calculation;
- Use of personal judgments assumptions and evaluations;
- Making comparisons;
- Use of tables

CHAPTER FOUR

4. DATA ANALYSIS AND INTERPRETATION

4.1 Profile and number of respondents per educational level

No.	Education level	Quantity	Percentage (%)
1	MSc./MBA	1	3.45
2	MSc.	12	41.38
3	MBA	1	3.45
4	BA	4	13.79
5	BSc.	5	17.24
6	Diploma (12+3)	1	3.45
7	Diploma (12+2)	2	6.90
8	High school (12)	3	10.34
	Total	**29**	**100**

4.2 Data Analysis and interpretation

4.2.1 Do storm runoff drainages often considered as part of the road way or a standalone project?

As Road way project	Standalone	Both	Based on the project	Total
15 (83%)		**1 (6%)**	**2 (11%)**	**18 (100%)**

The perception and understanding of most (83%) of the respondents (even those working i in design and construction offices) is that storm runoff drainages are part of roadway projects. Apparently, storm runoff drainages are designed to accommodate not only road pavement runoff but also flows from the adjacent catchment and upstream channels. Actually, due to topography of the area and trend of urban landscape where most surfaces are made impermeable, large volume of the rainfall (instead of infiltrating) runs off over the surface and either flow to the nearest downstream channels or pond at plain surfaces. The quantity and velocity of the storm runoff from the adjacent catchments is much larger than pavement runoff and it carries along debris and silts to the channel. Its design, thus, shall take into consideration all factors like topography, environment, soil type, catchment area, ambient weather etc. These and other technical factors as recommended by the urban drainage design manual should be the basis for storm runoff drainage design. Cross section, type, material and size of the channel will then be determined once magnitude and volume of the runoff is known. Therefore, the problem of overflow and overtopping are partly the outcome of not considering in the design the magnitude of flow from the adjacent catchment and partly sedimentation and blockage by rubbish notwithstanding size & type of the pipe. This implies that fundamental considerations in the design of drainages are overlooked hence overflow on road surface.

Figure 4.1. Storm runoff from adjacent area gushing to main road with rubbish, silt and mud (Courtesy: Fekadu Zeleke)

4.2.2 What are the main problems associated with storm runoff drainage?

Over topping/ overflow	Sedimen tation	Clogging by debris and litters	Inferior quality of drainage materials	Scouring / Erosion	Constructi on workmans hip	Others (please specify	Total
12 (67%)	**16 (89%)**	**18 (100%)**	**7 (39%)**	**6 (33%)**	**11 (61%)**		**18 (100%)**

Almost all of the respondents agree that the main problem of storm water runoff drainages is clogging by debris and rubbish whilst sedimentation, overflow, substandard workmanship & materials and scouring are other problems associated with drainage structures. Splash, skidding, loss of control, accident and respiratory tract infection are also problems related to storm runoff drainage. In Ethiopian context, where watersheds of many urban centers receive significant amount of annual rainfall with high intensity, control of runoff at source, flood protection and safe disposal of excess water/runoff through proper drainage facilities is very critical. With urbanization and subsequent introduction of impervious surfaces (like paved roads, parking lots, houses etc.), impermeability increases and consequently drainage pattern changes, concentration of flow increases, overland flow gets faster and as a result flooding occurs and environmental problems such as land degradation increases. Basically, drainage problems occur due to either design and/or construction faults. Drainage problems in urban areas include flooding, deterioration of road sections, land degradation, sedimentation, blockage of drainage facilities, water logging, etc.

Figure 4.2. Flooding & overflow along main road limiting vehicular movement (Courtesy: Fekadu Zeleke)

4.2.3 What are the major causes of drainage problems?

Insufficient study of soil type, topography and hydrology of the catchment area	Inappropriate Drainage channel type	Inadequate Drainage channel size, slope and cross section	Inadequate detail of drawings	Incompatibility of designs with standard and code of practice	Construction malpractice	Dumping of household garbage & litters into the channels by nearby residents	Others (please specify	Total
15 (83%)	8 (44%)	11 (61%)	4 (22%)	5 (28%)	9 (50%)	18 (100%)	1 (6%)	18 (100%)

Similarly all the respondents affirm that dumping of household rubbish into the channels, insufficient study of the catchment area, insufficient technical documents as well as inadequate channel sizes are identified as the main culprit in causing drainage related problems in the area. The finding indicates that there is no regulatory body as such that critically checks compliance of storm runoff drainage designs vis á vis all the requisite factors, policies, standards and guidelines. Offices rather check designs by their Engineers or in most instances engage consultants to prepare the designs and supervise implementation as per the scope and budget of the project. Thus, compliance and reference of all other factors will be left to the consultant who in most instances becomes reluctant to adhere as it involves significant time & cost for detailed site and environmental investigations. It is also compounded by absence of regular inventory of drainage channels, assets and furniture which if conducted could have helped to timely identify problems that influence proper function of the drainage channels and avoid careless construction practices and use of substandard materials. Lack of public awareness on solid waste disposal and to some extent absence of inspection encouraged residents to dump household rubbish in to the drainage channel. Therefore, involvement of regulatory body during design and construction as well as scheduled inspection of the channels is highly important and critical for proper function of the channels. Furthermore, unavailability of drainage master plan aggravated the situation where designers are left to their choice of inlet and outlet points. Essentially, drainage Master plans are intended to guide, direct and inform designers based on the location, volume and type as to where to collect, connect and dump storm runoff. Unfortunately, there is no dedicated office that deals particularly with storm runoff hence confusion as to who would prepare master plan for drainages.

4.3 Summary of the Data Analysis and Interpretation

a) Storm runoff drainage is considered as roadway project by most respondents including those working in design and construction offices

b) The main problem associated with storm runoff are identified (mainly) to be clogging by debris & rubbish, sedimentation and overflow

c) The causes of the problems are dumping of rubbish, inadequate study of the soil & topography, insufficient channel size and poor construction workmanship

d) The channel size for most of the drainage structures is $< \Phi$ 90 cm

e) Offices have ‘Urban storm Water Drainage Design Manual’, however, usage and reference to the manual in design and construction of drainages is very low

f) It is also asserted that there is no regular inventory of drainage channels, assets and furniture

g) There is no regular cleaning of drainage channels

h) There is no Drainage Master plan

CHAPTER FIVE

5. CONCLUSION and RECOMMENDATION

5.1 Conclusion

Storm water is a component of the total water resources of an area that should not be casually discarded but rather, where feasible, should be used to replenish that resource. In many instances, storm water problems signal either misuse of a resource (storm water) or unwise land activity (impermeability of surfaces…).

Development of storm water drainage system is not possible in isolation from other infrastructure and environmental sectors. Coordination is necessary between different departments, government and other stakeholders and planning should take cognizance of processes such as integration of the various activities carried out by each sector.

Storm water drainage planning, design and management activities shall ensure the participation of the people and other stakeholders at all levels. Environmental considerations such as soil erosion and sedimentation must also be taken in to account.

Roadway drainages, essentially, are built to prevent onsite water pooling over surface of the road and convey offsite storm runoff along the road or across using structures like culverts or bridges as warranted.

The drainage system in urban areas serves a number of purposes. The most important are: Prevention of flooding, discharge of polluted wastewater in a sanitary sewer and providing reasonable hydrological conditions for urban aquatic and terrestrial ecosystems.

However, from an environmental point of view it is unacceptable to discharge polluted wastewater directly into receiving water. This in combination with the land use features of the urban environment implies that the drainage of urban areas is complex, artificial and expensive.

5.2 Recommendation

i. Establish a legally mandated and dedicated drainage department in Ministry of works and Municipalities of Addis Abeba and regional towns to regulate, guide and monitor design and construction of storm runoff drainages and regularly conduct inventory of drainage assets and furniture

ii. Enforce use of drainage policy and update the policy to incorporate storm water management practices and sustainable urban drainage system

iii. Pervious pavements are one of the SUDS (sustainable urban drainage systems) used mostly for feeder roads, car parks and can also be used for other surfaces where there is no traffic or very light traffic. (to keep the natural balance, recharge…). It could consist of one of a variety of types of block, or could be a layer of porous asphalt. Blocks may be porous, allowing water to seep through them via pores in the material itself, or permeable, where the material is not porous but the blocks are laid in such a way that water can pass between them. Permeable blocks may fit tightly, with water passing through narrow slots between blocks, or may be laid with a pattern of larger voids which are filled with soil and grass, or gravel. Below the surface layer of blocks is a bedding layer of sand or small-size gravel, separated from the sub-base below by a layer of geotextile.

iv. Since administration of the city's infrastructure falls under the jurisdiction of the municipality, a municipality shall have a storm water management project that has the following four goals:

- ✓ To establish a dedicated office for the management of storm runoff
- ✓ To obtain a federally mandated permit to discharge storm water from the municipal separate storm sewer system to creeks and streams
- ✓ To plan, organize, and take steps to establish the foundation for a comprehensive storm water quality and quantity management program
- ✓ To develop and carry out a storm water utility to fund the storm water management program

v. Public awareness and education are the foundations of a successful urban storm water management program. From the program's inception and throughout its growth and service life, interaction with, and education of, the public is not an adjunct to the program's purpose; they are (or should be) a main purpose of the program. Public awareness and education shall be carried out in storm water management programs in two main ways: specific public awareness campaigns and ongoing "baseline" public information programs and activities. These two aspects differ in that a campaign has a beginning and an end, while the ongoing program goes through transformations but does not envision an ending. But, for either case, there are specific factors that should be kept in mind and methodologies that will make a storm water management program successful.

vi. The use of the procedures described in the 'urban storm water drainage design' manual will help in achieving reasonable uniformity in drainage network design for a given set of conditions. Therefore, use of manual should not be an alternate option but a mandatory practice for consistency and coherence to suggested procedures

vii. The highway facility should be designed to be compatible with existing drainage patterns. Hence, the design shall ensure that both the highway and the traveling public should be protected from the hazards of flooding.

viii. Municipalities should place a strict weekly schedule to clean up existing channels, which would significantly reduce any buildup of debris, siltation and help control dumping of rubbish and pollutants

ix. Municipalities should engage hydrologist, drainage Engineers and multi-disciplinary team to prepare a drainage masterplan for towns which will essentially; guide, direct and inform the public and designers based on the geology, topography, soil type, land use, right of way, local ordinance, geometry and geography of the catchment as to where to locate, collect, connect and dump storm runoff.

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7. APPENDIX

APPENDIX A

ANALYSIS OF STORM WATER RUNOFF DRAINAGES IN ADDIS ABABA CITY ROADS (CASE STUDY – CMC ROAD)

I. Introduction

Problems associated with storm run-off drainage are common occurrences in almost every road in Addis Ababa city. They overflow and inundate carriage way, walk way and houses adjacent to the road corridor. They cause traffic jam, accidents, scouring, erosion and health hazard that eventually result in unnecessary expenses and budget overruns. Thus, this questionnaire is prepared with an intention of collecting primary data on Storm Runoff Drainage with a view to analyze the cause and consequences of the problems.

II. Objective

- The objectives of this questionnaire are to:
- Identify the main problems of drainage structures through survey
- Identify the major causes of the drainage problems associated with storm runoff
- Find out the perceptions and responsibility of the major stakeholders in planning, construction and regulation of drainage structures and
- Suggest recommendations from the findings

The findings will be documented as a guideline for future reference and is hoped to assist regulatory bodies and other sector departments in review of implementation.

II. Request

With the above brief introduction, I kindly request those who consensually take part in filling out this questionnaire to contribute to this MBA research work by providing accurate and reliable information. All the information gathered here will only be used for academic purposes. Your prompt response to the questionnaire is highly appreciated.

Thank you!!

PROFESSIONALS SURVEY

i. Questionnaire for PROFESSIONALS working in Design, Construction and regulatory offices

Profile of Respondent

Position/ occupation ________________________________

Educational Background/Level ___________________________

Experience in the field _________________________________

Office ____

<u>Please circle your responses (Multiple responses are possible)</u>

1. Do storm runoff drainages are often considered as part of the road way project or a standalone project?

____

2. What is the catchment area of road way drainage?

   a. Pavement runoff b. Adjacent upstream flow c. Both

3. What are the common types of longitudinal road way drainages?

   a. Open channel b. Closed channel (culvert) with inlet

4. If open what type of channel it is?

   a. Trapezoidal b. rectangular c. other

5. What is the average size of the closed channel?

   a. Φ 90 cm b. > Φ 90 cm c. < Φ 90 cm

6. What are the main problems associated with storm runoff drainage?

   a. Over topping/ overflow

   b. Sedimentation

   c. Clogging by debris and litters

   d. Inferior quality of drainage materials

e. Scouring/Erosion

f. Construction workmanship

g. Others (please specify) ___________________________________

7. What are the major causes of drainage problems?

a. Insufficient study of soil type, topography and hydrology of the catchment area

b. Inappropriate Drainage channel type

c. Inadequate Drainage channel size, slope and cross section

d. Inadequate detail of drawings

e. Incompatibility of designs with standard and code of practice

f. Construction malpractice

g. Dumping of household garbage & litters into the channels by nearby residents

h. Others (please specify) __________________________________

8. Is there a regulatory body for design and construction of drainage structures?

a. Yes ________ b. No __________

Please specify, if yes __________________________________

9. When does the regulatory body involve?

a. On compliance checking of designs b. during construction

c. Both d. none

10. Do you use Urban storm Water Drainage Design Manual?

a. Yes ________ b. No __________

11. Do you think all standards stated in the manual are put in use in the design and construction of drainage structures?

a. Yes ____ b. No _____ c. Sometimes

12. What are the challenges in using design manual or ERA standards?

   a. Not widely available to professionals
   b. Reluctance to use them
   c. The office does not have it

13. Is there regular inventory and condition assessment of drainage structures?

   a. Yes _______ b. No _________

14. Who does the inventory?

   a. AACRA b. Municipality

   c. Water and sewage authority d. Other

15. Considering the magnitude and catchment of storm runoff, should it be channeled to sewer lines instead of road side drainages?

   a. Yes _______ b. No _________

16. Considering the sustainability and economic point of view, should drainages run separately from the sewer or combined?

____

17. Where does the storm runoff end up?

   a. Rivers b. Treatment center

   c. Cess pool d. Do not know

18. Is there a drainage master plan for Addis Ababa city?

   a. Yes _______ b. No _________

   c. Do not know

19. If No, who should prepare drainage master plan?

   a. AACRA b. A.A. Water and sewage Authority

   c. Municipality d. Master plan office

THANK YOU!!

RESIDENTS SURVEY

ii) Questionnaire for RESIDENTS living around the storm runoff drainage

Profile of Respondent

Position/ occupation ___________________________________

Educational Background/Level _______________________________

Residential area ____

How long have you lived in the area __________________________

Please circle your responses (Multiple responses are possible)

1) How do the road way drainages function in your area?

a. Properly c. Overflow and inundate the road

b. Clogged d. Not available

2) If there is a drainage structure, does it overflow its channels?

a. Yes _______ b. No _______

3) Does the overflow spew debris and noxious waste out on to the surface?

a. Yes _______ b. No ________

4) Does the overflow impede vehicular and other traffic movement?

a. Yes _______ b. No ________

5) What is the average time wasted by traffic during inundation?

a. 15 minutes c. 30 minutes

b. 1 hour d. > 1 hour

6) Is there sewer line that collects sewerage from households in your residential/working area?

a. Yes _______ b. No ________

7) Are there any drainage structures on feeder roads around your residential/working area?

a. Yes _______ b. No ________

8) Do the drainages on feeder roads collect all the storm runoff and feed it to?

a. Sewer line b. the channel at nearby trunk road c. Do not know

9) How frequent do workers come to clean the drainage lines?

a. Regularly c. Sometimes

b. Not at all

10) What do you think is the cause of blockade/clogging that resulted in overflow of the channels?

a. Household litters dumped into the channels

b. Silt and debris from upstream flow

c. Smaller size of the channel

d. All of the above

e. None of the above. Other cause. (Please specify)

____

11) What should the authorities do to protect people from dumping household wastes in to drainage lines?

a. Awareness creation to notify the consequences

b. Introduce penalty

c. Organize community members to keep watch and report to authorities

d. Please specify any other suggestion that will help curtail such problems

____

APPENDIX B

አዲስ አበባ ከተማ በሚገኙ መንገዶች ዙሪያ ያሉ የጎርፍ ማስወገጃ ቦዮች ላይ የሚደረግ ጥናታዊ ምርመራ

1. መግቢያ

በከተማችን ከጎርፍ ማስወገጃ ቦዮች በሚወጡ ፍሳሾች የሚከሡቱ ችግሮች ማለትም የመኪና እና የእግረኞች መንገድ መጥለቅለቅ፡ ከመስመሩ ወጥቶ በየመንደሩ ውስጥ የሚጎርፍ ፍሣሽ ወ.ዘ.ተ የተለመዱ ክስተቶች እየሆኑ መጥተዋል፡፡ ነገር ግን እነዚህ ፍሳሾች የመኪና ትራፊክ እንቅስቃሴን በማወክ የመንገዶች መዘጋጋት፡ ግጭት፤ የፍሳሽ መስመሮች መሸርሸርና መቦርቦር የጤና ችግርና አላስፈላጊ ወጪ በማስወጣት የከተማውን ውስን የምጣኔ ሃብት አቅም በማዛባት ላይ ይገኛሉ፡፡

በመሆኑም የዚህ ፅሁፍ ዋነኛ ምክንያት ከአካባቢው መረጃዎችን በመሠብሠብ የችግሮቹን መንስዔ ለማወቅና በጥናት የተደገፈ ምርመራና ግምገማ በማድረግ ችግሩን ለመቅረፍ የሚረዱ የውሳኔ ሃሳቦችን ለማቅረብ ነው፡፡

2. የጥናቱ ዓላማ

- ከጎርፍ ፍሳሽና ማስወገጃ ቦዮች ጋር በተያያዘ እየተከሡቱ ያሉ ችግሮችን ለማወቅ
- የችግሮቹን መንስዔ በጥናት ለመለየት
- በጎርፍ ማስወገጃ ቦዮች ግንባታ ዕቅድ፤ ፕላን፤ ቁጥጥርና ደንብ ማስከበር ዙሪያ የተሠማሩ የድርሻ አካላትን አስተያየትና አፈፃፀም ለመመርመር
- በመጨረሻም በጥናት የተደገፉ የውሳኔ ሃሳቦችን ለደንብ አውጪና አስፈፃሚ አካላት ለማቅረብ ነው፤፤

3. ትብብር ስለመጠየቅ

ከላይ በመግቢያውና በዓላማው ላይ እንደተገለጸው ከዚህ ጋር የተያያዘው መጠይቅ የማስተርስ ዲግሪዬ ጥናት አካል በመሆኑ መጠይቁን በፈቃደኝነት ለመሙላት የምትሳተፉ ግለሠቦች ትክክለኛና እውነተኛ መረጃ በመስጠት

እንድትተባበሩኝ በማክበር እየጠየቅኩ መረጃዎቹ ለምርምርና ጥናት አገልግሎት ብቻ የሚውሉ መሆኑን አሣውቃለሁ፡፡

አመሠግናለሁ!!!

<u>ከጎርፍ ማስወገጃ ቦዮች ጋር የተያያዘ ለነዋሪዎች የተዘጋጀ መጠይቅ</u>

የግል መረጃ

የሥራ ድርሻ/ሙያ ______________________________

የትምህርት ደረጃ ______________________________

የመኖሪያ ሥፍራ ______________________________

በሥፍራው ላይ ምን ያህል ጊዜ ቆዩ ______________________

<u>እባክዎ ምላሽዎትን ያክብቡ (ከአንድ በላይ ምላሽ መስጠት ይቻላል)</u>

1) በመኖሪያ አካባቢዎ የሚገኝ የጎርፍ ማስወገጃ ቦይ አለ፡፡ ካለ ምን ዓይነት ነው

ሀ) ከድፍን ቱቦ የተሠራ ዝግ ነው ለ) ክፍት ነው ሐ) የለም

2) በመኖሪያ አካባቢዎ የሚገኘው የጎርፍ ማስወገጃ ቦይ እንዴት እያገለገለ ይገኛል

ሀ) በአግባቡ ለ) ተደፍንዋል

ሐ) ጭራሽ የለም መ) እየሞላ አካባቢውን ያጥለቀልቃል

3) የጎርፍ ማስወገጃ ቦዩ ይደፈናል

ሀ) አዎ ለ) አይደፈንም

4) ቦዩ የሚደፈነው በምን ምክንያት ይመስልዎታል

ሀ) ከአካባቢው በሚጣለው ጥራጊ ቆሻሻ ለ) የቦዩ መጠን በማነሱ

ሐ) ጎርፉ ሰብስቦ በሚያመጣው ደረቅ ቆሻሻ መ) ሌላ ምክንያት (እባክዎ ይግለፁት)

____

5) ቦዩ ሞልቶ አካባቢውን ሲያጥለቀልቅ ደረቅ ቆሻሻና መጥፎ ጠረን ያለው ፍሳሽ ይለቃል

ሀ) አዎ ለ) አይለቅም

6) ቦዩ ሲሞላ መንገዱን በማጥለቅለቅ የሠውና የመኪና እንቅስቃሴን ያግዳል

ሀ) አዎ ለ) አያግድም

7) የሚያግድ ከሆነ በአማካይ ለምን ያህል ጊዜ እንቅስቃሴ ያውካል

ሀ) ለ15 ደቂቃ ለ) ለ30 ደቂቃ

ሐ) ለ1 ሠዓት መ) ከ1 ሠዓት በላይ

8) የሽንት ቤት ፍሳሽ ማስወገጃ ቦይ በአካባቢዎ ይገኛል

ሀ) አዎ ለ) የለም ሐ) አላውቅም

9) የሚገኝ ከሆነ የራሱ የሆነ የተነጠለ ቦይ አለው ወይስ ከጎርፍ ማስወገጃ ቦይ ጋር ይቀላቀላል

ሀ) የተነጠለ ቦይ አለው ለ) ከጎርፍ ማስወገጃ ጋር ይቀላቀላል

ሐ) አላውቅም

10) በአቅራቢያዎ የሚገኘው የጎርፍ ማስወገጃ ቦይ ከዋናው መንገድ የፍሳሽመስመር ጋር ይቀለቀላል

ሀ) አዎ ለ) አይቀላቀልም

ሐ) አላውቅም

11) የፅዳትና ፍሳሽ ሠራተኞች በምን ያህል ጊዜ እየመጡ ቦዩን ያፀዳሉ

ሀ) ዘወትር ለ) አልፎአልፎ

ሐ) መጥተው አያውቁም　　　　መ) አጋጠመውኝ አያውቅም

12) ከአካባቢ የሚጣል ቆሻሻ በአብዛኛው ቦዮችን እየደፈነ ይገኛል፡፡ ይህን ለማስወገድ ምን መደረግ አለበት ብለው ያስባሉ

ሀ) ተከታታይነት ያለው የማሳወቅ ዘመቻ

ለ) ቅጣት መጣል

ሐ) ነዋሪውን አደራጅቶ ክትትልና ጥቆማ እንዲያቀርብ ማድረግ

መ) ሌላ (የተለየ ሃሣብ ካለ አባክዎ ይግለፁ)

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8. BIOGRAPHY

My name is Fekadu Zeleke Ayele and was born in 1969 in a thriving town called Wolliso (a.k.a. Ghion) situated in west of the capital Addis Abeba at 110km distance. I attended my elementary and vocational secondary schools there and acquired certificate in Electricity. I joined Addis Abeba University, Building College in 1986 and graduated in 1989 with advanced Diploma in Building Engineering.

Since then I have been working in various organizations in different occupational level/capacity hence have long and diverse experience. I attended Road maintenance management course in Botswana institute of Development management (IDM) and have also acquired Honors graduate diploma in Business management and Administration from Cambridge University through distance education.

In 2012 I joined Techzone Engineering and Business College and acquired Bachelor of Science (BSc.) in Construction Technology and Management.

My inspiration to pursue further education in Construction Management is due to its broad applicability in all construction sectors and its wider scope from the dynamics of management to latest construction technologies.